Assessing Long-term Effects of Municipal Solid Waste

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'Waste Management in the Focus of Controversial Interests'
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Introduction

Goal of product-oriented LCA:

- Make estimates of the total environmental damage potential of a product to point out least-burdening options

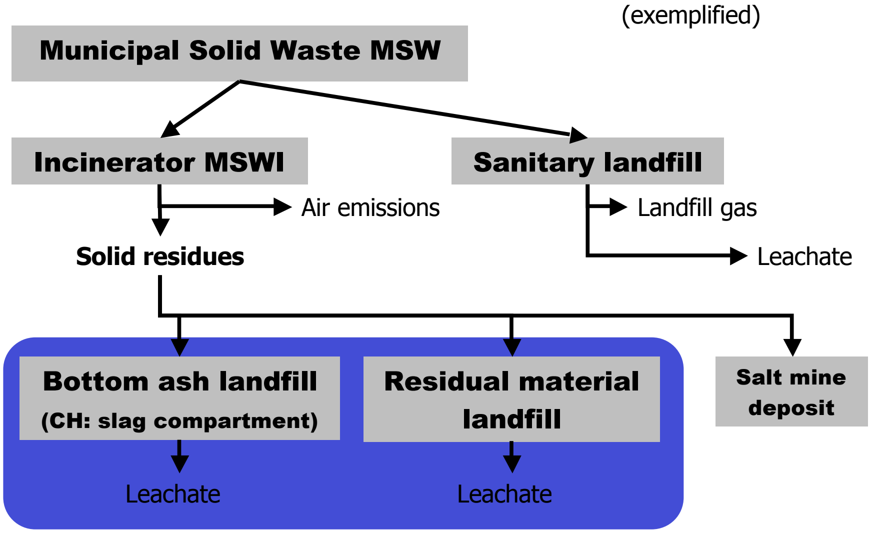
Waste disposal models in product-oriented LCA

- Make estimates of the burdens attributable to the disposal of the assessed product (e.g. burdens from disposal of 1 kg floor board)
- used to complement the 'cradle-to-grave' assessment (e.g. manufacture + use + disposal of 1 kg floor board)

In the following the disposal models created for the large Swiss Life-Cycle Inventory database ecoinvent are presented (cf. www.ecoinvent.ch)

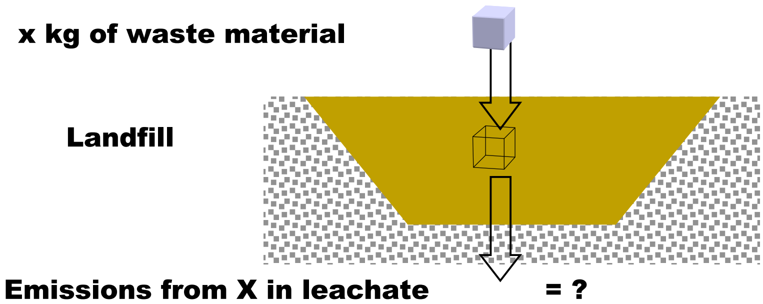
Process chains in waste disposal

(exemplified)



Landfill emissions in LCA

- What emissions are created from the landfilling of a certain waste product?



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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.

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Earlier landfill models

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 or to be proportional to the long-term available fraction.

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. Not based on theoretical models alone, but also on observed behaviour in the field.

Waste-specific emissions

Pollutants are assessed as chemical elements (e.g. copper, cadmium, zinc etc.). Calculation of waste-specific emissions:

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

with X = chemical element and n = output route

TK = transfer coefficient

Transfer coefficients (TK) are derived from average operation and describe the behaviour of that disposal technology.

Resulting emissions are:

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

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 groundwater (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 surface
- The time frame for leachate 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.

Uncertainty of transfer coefficients

Data in ecoinvent 2000 is recorded as a mean value, as well as an estimated 95% percentile range (worst / best case).

'Worst case' transfer coefficient

All material is emitted from the landfill: TK_{worst} =100%

Mean transfer coefficient

Emissions of the first 60'000 years are heeded

= estimated time until the next Swiss midland-covering ice age.

The Swiss ecosphere will be totally remodelled

≅ *"ecological planning horizon"* of LCA

'Best case' transfer coefficient

Implied from mean and worst case and chosen lognormal distribution type

Inventory time frames

To have a rough idea of when emissions are occurring two temporal periods are distinguished in the ecoinvent inventories:

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):

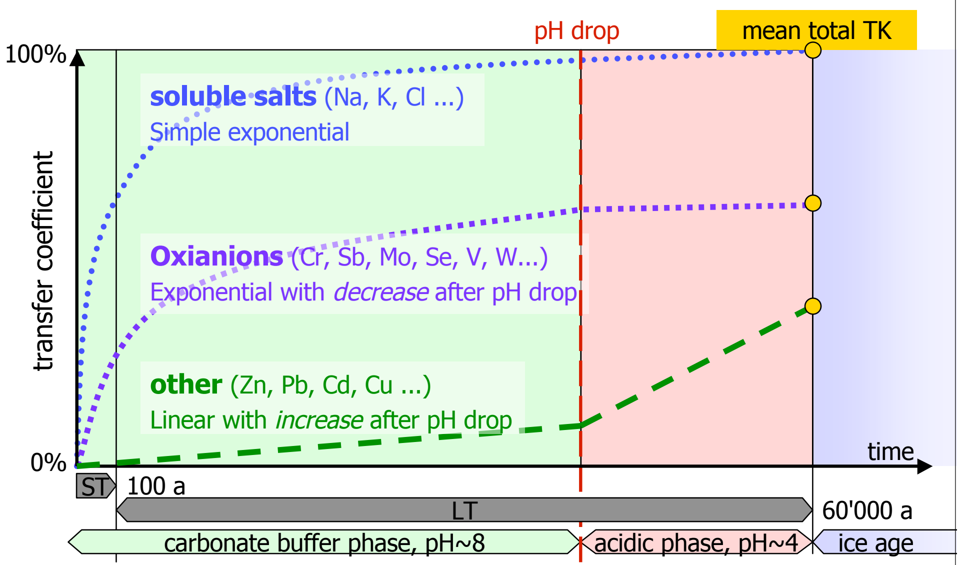
Occur 100 years or more after the process has been started. Unlimited, open-end period.

→ The landfill models use two sets of TK to calculate emissions:

ST-TK for emissions 0 to 100 years after present

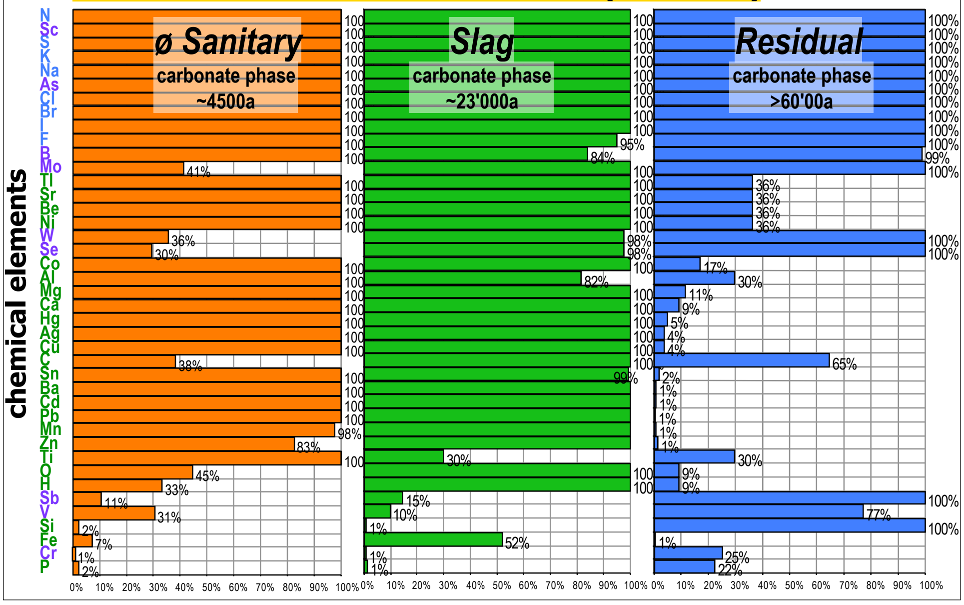
LT-TK for emissions 100 to 60'000 years after present

General types of transfer dynamics



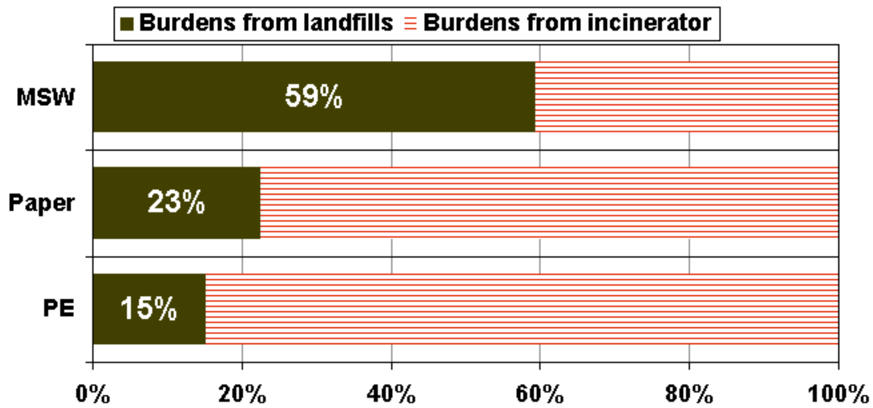
Transfer coefficients comparison

Mean total landfill transfer coefficients (0-60'000a)

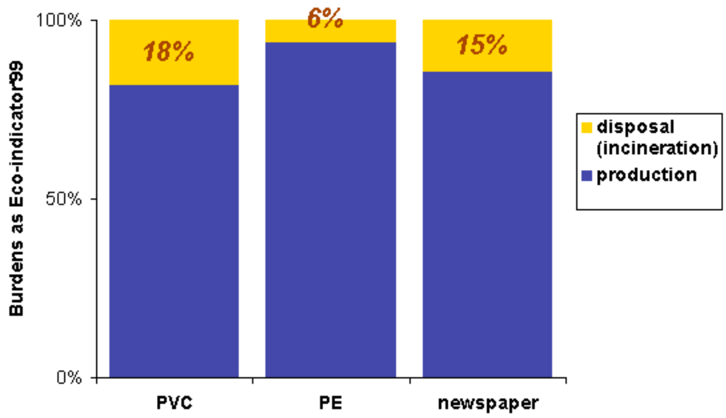


Disposal process LCA result

Burdens from municipal incineration and subsequent landfilling of residues, in Eco-indicator'99 points



Contribution of disposal to the product life-cycle



B. Valuation of long-term emissions

State-of-the-art LCA records burdens:
- along the whole product life-cycle chain of processes
- regardless of national or geographical boundaries
- regardless of temporal boundaries
- regardless of pollutant concentrations

All these burdens are recorded in order to avoid burden shifting:
- from one life-cycle phase to another (e.g. from use to manufacture)
- from one nation to another
- from past or present into the future
- from one large polluter to many distributed sources

→ Also life-cycle burdens of the future must be included in LCA, in order to avoid burden shifting onto future generations.

Discounting of long-term burdens?

Discounting (negligence) of future *benefits* is common in economy.

By symmetry, some propose discounting of future *burdens* in LCA.

→ Hellweg et al.* have shown that discounting future burdens for pure time preference is **unethical**

→ Allowing LCA to count mere burden shifting into the future the same as the *prevention* of burdens obviously clashes with common concepts of **environmental sustainability**

Some wish to discount burdens from landfills in LCA because they seem too uncertain.

→ *Many* contributions in LCA have large uncertainties. Selectively neglecting one allegedly uncertain contribution but keeping others is not a sound concept.

* Hellweg S. et al. "Discounting and the Environment: Should Current Impacts be weighted differently than Impacts harming Future Generations?" Int. J. LCA, 2002

Goals & Improvements

Discounting future burdens is detrimental to the goal of LCA, which is to make damage potentials visible.

Some subjective notions are not compatible with the conceptual goals of LCA and are therefore - despite generous tolerance of alternative viewpoints - not admissible in LCA.

Of course the approximate landfill models presented here can and should be improved. Uncertainty in models shall not be used to *exclude* contributions. A coarse estimate is *always* better than a blind spot:

"Errors using inadequate data
are much less than those using no data at all."
Charles Babbage (1792-1871)

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 modelling improvements are well possible
  (e.g. adaptations from LCIA soil fate models?)
- Estimates of future emissions from landfills are difficult to make. But in order to be in accord with goals of environmental sustainability and common ethical values, LCA should not discount burdens to future generations.
  → No discounting of future burdens

Free online paper

Recent publication on my ecoinvent disposal models

Doka, Gabor & Hischier, Roland
"Waste Treatment and Assessment of Long-Term Emissions"
International Journal of LCA, 10 LCA (1) 2005, p. 77-84

Full paper, available as free PDF from:

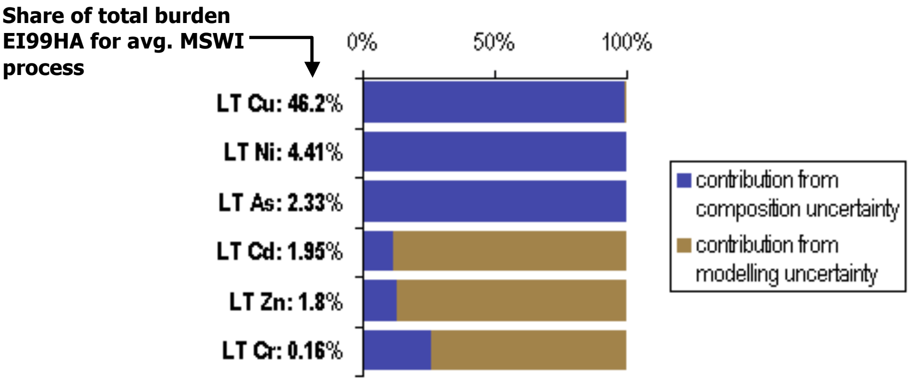
www.scientificjournals.com/sj/lca/Abstract/ArtikelId/7073

Thank you for your attention

Contributions to uncertainty

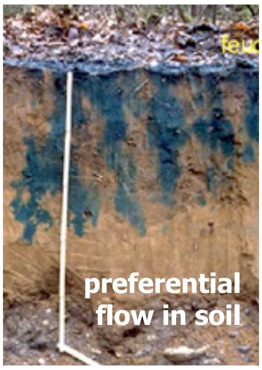
What are the main contributions to uncertainty?

1. Variability of waste composition
2. Variability of models (TKs in MSWI and landfills)



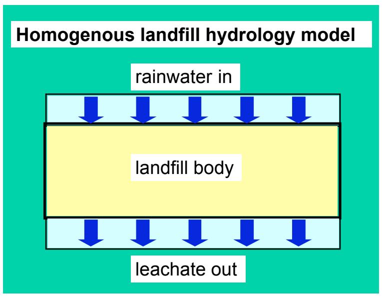
Preferential Flow

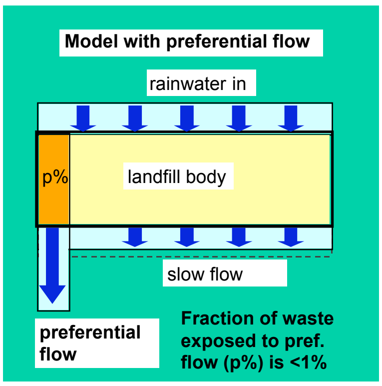
Infiltration water does not flow homogeneously through a landfill. A fraction of the water uses "quick routes" while the rest flows through the matrix.

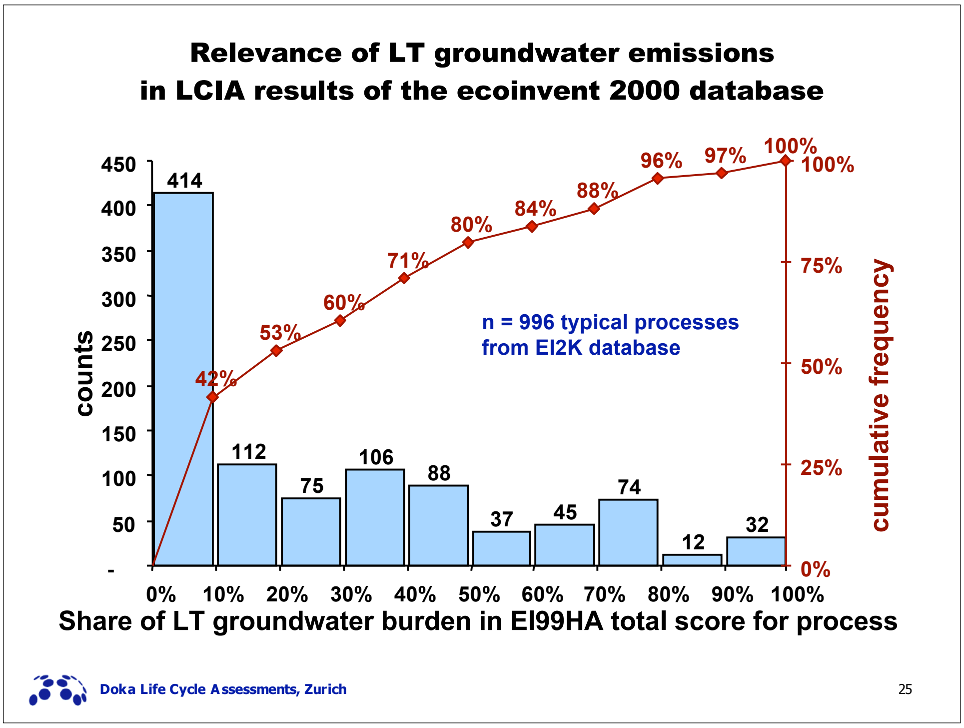


If part 'preferential leachate' flows more quickly, then 'matrix leachate' must flow slower than a homogeneous model would predict to maintain mass balances

This slows down weathering processes







Relevance of LT groundwater emissions
in LCIA results of the ecoinvent 2000 database
450
400
350
300
250
200
150
100
50
-
counts
414
112
75
106
88
37
45
74
12
32
42%
53%
60%
71%
80%
84%
88%
96%
97%
100%
n = 996 typical processes
from EI2K database
100%
75%
50%
25%
0%
cumulative frequency
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Share of LT groundwater burden in EI99HA total score for process
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