SUBJECTIVE VALUATION:
THE EXAMPLE OF LONG-TERM EMISSIONS IN THE LIFE CYCLE ASSESSMENT OF WASTE DISPOSAL SYSTEMS

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Comprehensive Life Cycle Assessment (LCA) studies of waste disposal processes show that long-term emissions from landfills – i.e. after 100 years – significantly contribute to the overall environmental impact potential. Motivations for considering or discounting long-term impacts are subjective and cannot be based on natural science knowledge. The goal of environmental sustainability efforts suggests that LCA should always display all emissions and impacts regardless of their temporal occurrence, while discounting should only be applied in sensitivity analysis.

The life cycle of waste

A comprehensive Life Cycle Assessment of municipal solid waste incineration should include the processes displayed in Figure 1. This set-up is suitable for generating generic LCI data, e.g. to complement LCI inventories of the *production* and *use phase* of products with *disposal* in a typical municipal solid waste incinerator.

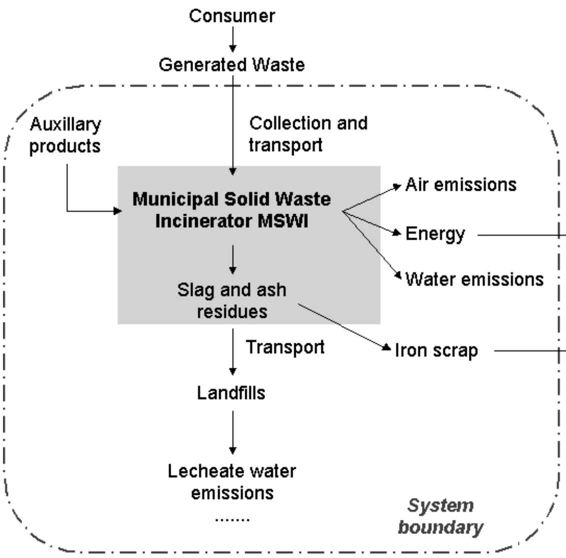

Figure 1 ***System boundaries for the LCA of municipal solid waste incineration.***

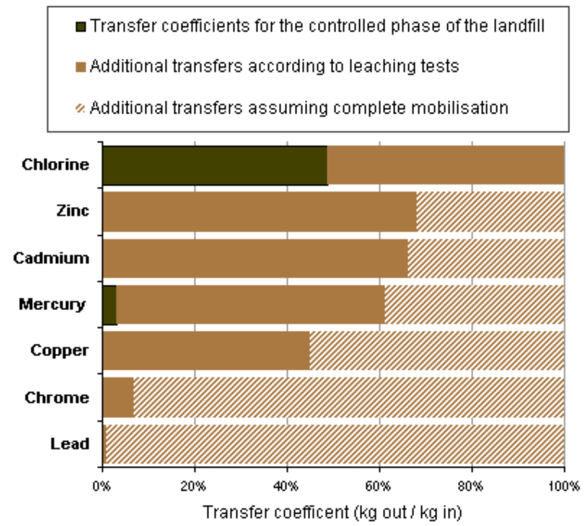

Figure 2 ***Transfer coefficients for a selection of elements to calculate emissions from slag landfills***

The problem of long-term emissions

Landfills emit persistent substances such as heavy metals to the environment for very long time periods – possibly hundreds of thousands of years. The long-term leaching behaviour of landfills has two implications for the modelling work (Finnveden et al. 1995): First, the emissions must be predicted because no measurements can be made concerning emissions in the far future. Second, a choice of the time frame has to be made. This choice of the temporal system boundary is a relevant key question, because it influences to a large extent the type of model and the kind of information which is most suitable for the modelling of the landfill. Existing models vary significantly in regard to the temporal system boundary, which has a strong influence on the sum of anticipated emissions from landfills. The range of time horizons considered varies from a few decades (van der Ven et al., 1998) to infinity (Sundqvist et al. 1997, Hellweg et al. 2002).

In the following, some simple model options will be proposed predicting the mass of pollutant released in the future:

1. Measurements at landfill sites (Figure 2, dark columns): Several studies have pointed out that the leachate composition and the quantity of emitted pollutants may vary considerably with time (Ludwig et al. 2000, Johnson et. al. 1998, Johnson et. al. 1999). Therefore, long-term extrapolations should not be made on the basis of field measurements. Data available from *field measurements* have been used to extrapolate the emissions occuring during the controlled or surveyed phase of the landfill[1]. Based on these data, transfer coefficients[2] can be calculated.

2. Leaching tests (Figure 2, light columns): The long-term emission potential (several decades to ten thousands years) has been estimated using *leaching tests* from the landfilled material, such as those proposed by van der Sloot (Van der Sloot et al. 1994). The test results have been used to derive a second set of transfer coefficients (ESU 1996).

3. *Declaring all landfill ingredients as future emissions (*Figure 2, light and hatched columns). Many landfill experts (e.g., Bäverman et al 1999, Bjoerklund 1998, Finnveden 1999, Finnveden 1996, Sabbas et al 1998, Sundqvist et al. 1997) assume that – given enough time – *all* material in a landfill will eventually be mobilised and released to the environment. This would simply mean to set all transfer coefficients to water equal to 100%.

In Figure 3 the results from a Life Cycle Assessment of the incineration of average municipal solid waste (MSW) in a modern Swiss incinerator are shown**[3]** (Hellweg et al. 2002, ESU 1996). The several damage categories displayed originate from three different LCA valuations methods: Eco-indicator'99 EI'99 (Goedkoop et al. 1999), the new CML'01 (Guinée et al. 2001), and Critical-Surface-Time'95 CST'95[4] (Jolliet et al 1995. The total damage is made up from three contributions. The first two contributions are defined as 100%. These are, first,

- *Short-term emissions (dark columns)* including air emissions from combustion, water emissions from flue gas treatment, burdens from collection and production of auxiliary materials, water emissions from slag, and residue landfill leachate *during their controlled phase* (less than 75 years, see landfill model step 1 above), and, second,
- *Long-term emissions* to the water *(light columns) after the controlled phase according to leaching tests (several decades to ten thousands of years,* see model step 2 above)[5].
- The third contribution (light and hatched column) exceeding the 100% sum shows the increase in the burdens if a total release were considered in the LCA (model step 3 above)[6].

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[1] For landfills of incineration residues (slag, ahes) the controlled phase is less than 75 years.

[2] Transfer coefficients represent the relation between the input residue and the output to water, air, and solid residues (assumed as permanently stored in the landfill). They are used to estimate emissions specific to certain waste material compositions.

[3] Burdens from incineration are fully allocated to the burned waste. No allocation shares are placed on the produced energy or iron scrap, as they are only a by-product of waste incineration.

[4] CST'95 consists of several damage categories. Full aggregation is achieved here by weighing all damage categories with unity (w =1), except for land use (w = 2.73) and energy and resources (w = 55.1) (Doka 2002).

[5] It might be interesting to note that the burdensome long-term landfill emissions – mainly heavy metals – only make up approx. 3% by weight compared to the mass of the incinerated waste.

[6] These additional burdensome landfill emissions make up approx. 9% by weight compared to the mass of the incinerated waste.

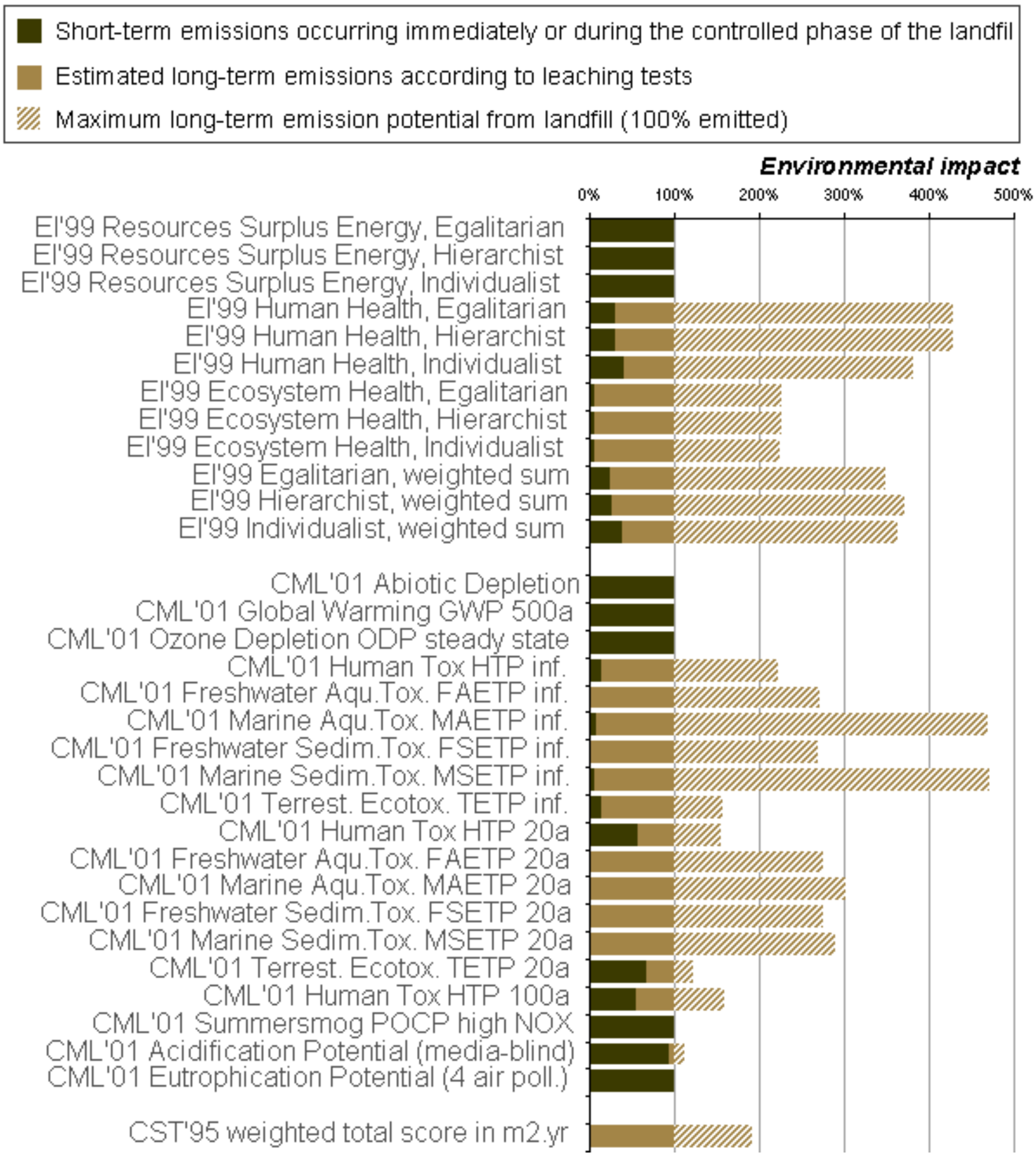

Figure 3 ***Results from an LCA of the incineration of MSW in Switzerland according to three different LCIA valuation methods. The damages from short-term emissions and estimated long-term landfill emissions are set to 100%. Columns exceeding the 100% margin signify potential damage increases if all landfilled material is mobilised.***

It is obvious that for many damage categories – especially toxicity potentials – the long-term leachate emissions from landfills are significant or even dominant. The most important long-term emissions are copper, cadmium, zinc, mercury, and antimony. The question of this paper is:

Within LCA, how should we deal with emissions occurring during long-term time frames?

More to the point, we are interested in the relationship between short-term emissions and long-term emissions. Shall we *include* long-term emissions in the assessment? When it comes to Life Cycle Impact Assessment (LCIA) shall we regard long-term emissions as being equal to short-term emissions in their damage potential or should there some relative weighting be involved?

Within the framework of LCA it has been common practice to neglect space or time issues. For example, ISO 14042 states in chapter 8 *"LCIA typically excludes spatial, temporal, threshold and dose-response information, and combines emissions or activities over space and/or time."* (ISO 14042. This implies that this kind of information is also disregarded in the LCI stage of LCA, i.e. emissions are inventoried regardless of their time of release. All emissions are treated as if they would be released at the reference point of time[7] and within one reference geographic region[8]. LCA practice currently lacks the tools to model damages to *future* environments from future emissions. Hence, as the *default in LCA*, future emissions are included in the assessment without any kind of weighting and are treated just like short-term emissions[9]. In the face of the LCA results of landfills with a strong influence of long-term emissions, the default procedure of avoiding temporal discounting might be worth to be reconsidered.

Quantitative discounting

A pragmatic way to differentiate time scales of emissions quantitatively would be the use of a *discount rate*. The discount rate weighs future emissions as a function of their time of release. The concept of temporal discounting originates and is widely applied in economics (Pearce 1983). Quantitative temporal discounting in the framework of LCA is further discussed in Hellweg et al. (2003 and 2000).

$$D = \sum_{t=0}^{\infty} (d_t * \frac{1}{(1+r)^t}) \quad (1)$$

where D is the time-adjusted total impact of pollutant X, d_t represents the impact of an emission occurring at the time t, r is the discount rate, and t is a parameter of time[10]. By convention, the unit of time is given in years.

The *discount rate r* in Equation 1 determines how future emissions are weighted against present emissions:

- A positive discount rate (e.g., r = +5%) weighs present and short-term emissions higher than future and long-term emissions.
- A negative discount rate (e.g., r = -1%) weighs present and short-term emissions lower than future and long-term emissions.
- A neutral discount rate (r = 0%) weights present and future emissions equally.

The equation above is the common way to perform temporal discounting. Other procedures are imaginable. To avoid mathematical discussions in the following, the beliefs and reasoning behind different forms of discounting will be discussed qualitatively.

To count or to discount?

Some of the possible arguments that support one of three conceptions are stated in the next section.

Concept 1	*Positive temporal discounting*	Future emissions are to be weighted *lower* than present emissions
Concept 2	*No discounting (the default in LCA)*	Future and present emissions are to be weighted *equally*
Concept 3	*Negative temporal discounting*	Future emissions are to be weighted *higher* than present emissions

Concept 1. Reasons to weigh future emissions **lower** *than present emissions*

1. In economics, discounting future monetary benefits is done, e.g., because an individual might have a pure time preference. He/she rather has the profits now, than later. One reason for that preference is that the further we go into the future the more the individual might be unable to take ad-

7 The reference time point is usually the present with the current environmental state.

8 Currently, the reference geographic region depends on the LCIA valuation method and can be e.g., Switzerland, Netherlands, or Western Europe.

9 However, also encountered are hard *temporal cut-offs*, i.e. all emissions after a certain time span, e.g., 150 years, are completely neglected, which is a form of temporal discounting. But, within the considered period usually no temporal discounting is performed.

10 This formula is only applicable to immediate damages. For emissions exhibiting long timeframes of impact after the release, the impact dynamics need to be included in discounting too.

vantage of these profits because there is an increasing probability that the individual has died[11] (Hofstetter 1998). By symmetry, future costs can also be subject to discounting. For example, costs that arise after I'm dead do not really bother me. By this reasoning it can be argued, that future environmental burdens are less bothersome than present burdens. Individual discount rates can be quite high (e.g., +15% per year) virtually neglecting everything after a few decades.

2. Another reason for pure time preference is impatience. Even within short time spans, where the risk to die is unchanged, people usually prefer immediate profits to future profits.

3. Opportunity costs: In economical sciences, it is usually assumed that productivity grows with time. This capital growth can be observed, e.g., on the financial markets, where interest rates are usually greater than 0%. Therefore, a certain amount of money *today* will be more valuable in the future than the same amount in the future. Opportunity costs are discussed in more detail in Hellweg et al. (2003).

4. Diminishing marginal utility. The relative increase of utility or usefulness of one additional unit of consumption, i.e. the marginal utility of consumption, is generally assumed to *decrease* with increasing income. For instance, for a family living at the poverty level an additional Euro income is assumed to have a higher utility than for a millionaire. A person with a perspective of increasing future individual wealth will attach less weight to additional future gains and, therefore, discounting is needed.

5. Similar arguments as in the previous points 1 to 4 can be put forward in accordance with the *social* discounting rate. Here however the argument goes back to uncertainties concerning the *whole society* and not only a single individual, e.g. the uncertainty of going extinct. This uncertainty is naturally much lower and social discounting rates are therefore much closer to zero (e.g., +2% per year). Also in social discounting there is pure time preference, as a society often values its present and familiar members higher than unknown future members.

6. The environmental damage could be prevented in the future by remediation, if reversible. The money for remediation could be invested on the capital market. A person with a positive view towards market economy expecting a continuous economical growth might therefore discount.

7. The uncertainties are too big: Too little is known about the long-term landfill behaviour to estimate leachate emissions accurately. Similarly, the future environment might be significantly different from today's and damages to such a changed environment cannot be accurately predicted. A *risk-seeking* personality will find a present and certain damage more important than a future and less certain damage, and therefore weigh present emissions higher than future emissions.

8. An extreme temporal discounting or temporal cut-off can occur already before the LCIA step in the Life Cycle Inventory (LCI) for pragmatic reasons: The models used to describe landfill processes might not be designed to calculate future emissions. E.g., some landfill models have a time horizon of a few decades and ignore all further developments[12]. This however is not a proper reason for discounting but just a current pragmatic barrier in calculating LCI results.

Concept 2. Reasons to weigh future emissions and present emissions equally

9. Causality: leachate emissions are caused by waste materials and should be fully accounted for.

10. "Our service, our responsibility": We have the use of the utility, we cause the damage, we should be held responsible. 'Polluter pays principle' as prescribed by Swiss environmental law (SAEFL 1986).

11. Within the framework of sustainability, we should not consider damages to future generations less important than damages to the present generation. Doing so would undermine the notion of sustainability.

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[11] This argument can also be stated in the forms that every generation has its own problems, and our generation should only be bothered with its own problems.

[12] Usually the reason for this is choice of temporal cut-off the uncertainty in predicting future landscape and climatic developments.

Concept 3. Reasons to weigh future emissions* higher *than present emissions

12. Likeliness of increasing background environmental burden. Dose-effect relations typically have positive rate increases (positive curvature): One kilogram at low background-doses usually causes less severe damages than one kilogram at higher background-doses. Put in other words, one kilogram pollutant released today is probably less severe than one kilogram pollutant in a more critically polluted future. A future emission can therefore cause a higher burden per kilogram than today.
13. Due to increases in population density, the release of one kilogram of pollutant in the future will affect more people's health than presently.
14. Future releases often represent an uncertain and/or poorly manageable risk. A *risk-avoiding* personality will find a future and uncertain release less desirable than a present and certain release, and therefore weigh future emissions higher than present emissions.
15. One could argue that future generations might be compensated financially for the environmental impact. This compensation should be high enough to satisfy those damaged. The necessary money could be invested on the capital market. However, considering that environmental "goods" might become very scarce while monetary wealth might increase in the future, this compensation cost could be very high, even approaching infinity, i.e., people who do not lack money might demand a very high compensation for an additional risk to their health.

The answer is – must be – subjective.

These answers to the question 'How to weigh future emissions as compared to present emissions?' are value-laden: they cannot be answered on a natural science or engineering based knowledge. Personal, social and cultural preferences, moral and ethics influence the possible answers: the answers are always subjective (Finnveden 1997). This, however is but one example of a value laden question in the course of an LCA[13]. Subjectivity is, however, not without structure or logic. It can be examined whether the arguments put forward in the previous section are compatible with the conception of LCA.

Is discounting of future damages compatible with the aims of LCA?

Why do we perform LCA at all? LCA is usually a tool to develop less environmentally burdening products and services or optimise ecological efficiency. The reason for that is the insight of producers or consumers that present consumption levels in developed countries are unsustainable: Consumption at present level with these impacts could not be sustained for an indefinite time. The notion of sustainability includes the concept that the present generation should not fulfil its needs while jeopardising the means for the future generation to fulfil their needs. LCA is a tool for the environmental part of this sustainability discussion by pointing out less burdening options.

Some of the arguments put forward to argue in favour of temporal discounting are in obvious disregard of this understanding of LCA – especially the first argument in concept 1. A pure time preference with a positive value implies that future people do not have equal rights as current people (Finnveden 1997). Furthermore, it "is in the egoistic interests of present persons, those responsible for creating the waste, not to bear the consequences of their actions and instead to force those consequences on others who do not deserve them. Such an egoistic position is not ethically defensible" (Shrader-Frechette 2000). It is also debatable whether a notion based on the probability of *a society going extinct* should be applied for a purpose aimed to secure the well-being of future societies. There is a chance of a self-fulfilling prophecy: If our generation keeps on generating future burdens and discounts them in its efforts to decrease environmental burdens on the grounds that a future society might not be there anymore, we are actually creating a burden that is prone to increase the chances of a future society actually collapsing.

It seems that the current default in LCA, which is not to discount any future burdens and use a zero discount rate, is certainly a justifiable procedure. LCA aims at displaying potential damages to *create a motivation* to reduce the risk of those damages actually happening. So, LCA needs to *show* those

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13 Others include goal setting, system boundaries, choice of allocation criteria, selection of damage indicator(s).

damage potentials and not obscure them. Otherwise, incentives to optimise burdening technologies would disappear (Steen 1999).

Uncertainty

However, the doubtless huge uncertainties especially concerning very long-term emissions after thousands of years need to be addressed. Proper uncertainty calculations are certainly desirable to deal with this issue. In LCIA different arguments clash on the consequences of uncertain data (i.e. point 7 vs. 14). Here again it can be argued, that LCA is usually a tool of prevention and should heed the precautionary principle. Consequently, the negligence of important but uncertain damage contributions seems not appropriate.

Conclusion

Long-term leachate emissions from landfills pose a substantial environmental burden potential. Negligence of these emissions in the LCI poses a clear risk of underestimating damage potentials. Landfill models in LCA are coarse and the uncertainties introduced are considerable. Nevertheless a proper LCI should also contain long-term emissions.

In LCIA there might be a number of subjective reasons to exclude long-term emissions or weigh them lower than present emissions. However, it can be argued that we should not disregard damages to future generations. This would be contradictory to the aims of environmental sustainability, which LCA is a tool for. The current default practice in LCA to sum up environmental burdens without temporal discounting is appropriate. However the frequently encountered practice of landfill modelling with temporal cut-offs[14] should be avoided and replaced with *at least* a sensitivity analysis including complete emission during a very long time frame.

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[14] I.E. neglecting all landfill emissions after a certain period of time e.g., 100 years.

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