EXPERIENCES ON THE USE OF LCA-MODELING (EASEWASTE) IN WASTE MANAGEMENT


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INTRODUCTION

EASEWASTE (Environmental Assessment of Solid Waste Systems and Technology) is a new LCA-based decision support tool within waste management. The model, which is developed by the Technical University of Denmark, calculates waste flow, resource consumption and environmental emissions from waste management systems and provides a complete impact assessment in terms of potential global warming, ozone depletion, photochemical ozone formation, acidification, nutrient enrichment, ecotoxicity and human toxicity. The model furthermore has introduced two impact categories: Spoiled Groundwater Resources and Stored Toxicity. Table 1 shows the units and normalization references for the impact potentials that are available in EASEWASTE. The model is flexible, user-friendly and provides default data for waste composition, collection, transport, various treatment processes, landfilling, use on land, recycling, utilization as well as upstream and downstream processes (for example electricity consumption and heat production)

Table 1: Potential impact categories included in EASEWASTE (partly after Kirkeby et al., (2006a) and DEPA, (2005))

<table>
<thead>
<tr>
<th>Potential Impact Category</th>
<th>Acronym</th>
<th>Unit</th>
<th>Physical basis</th>
<th>Normalization reference EU-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming, 100 years</td>
<td>GW100</td>
<td>Kg CO₂-eq./person/yr</td>
<td>Global</td>
<td>8700</td>
</tr>
<tr>
<td>Photochemical Ozone Formation</td>
<td>POFl</td>
<td>kg C₂H₅-eq./person/yr</td>
<td>Regional</td>
<td>25</td>
</tr>
<tr>
<td>Ozone Depletion</td>
<td>OD</td>
<td>kg CFC-11-eq./person/yr</td>
<td>Global</td>
<td>0.103</td>
</tr>
<tr>
<td>Acidification</td>
<td>AC</td>
<td>kg SO₂-eq./person/yr</td>
<td>Regional</td>
<td>74</td>
</tr>
<tr>
<td>Nutrient Enrichment</td>
<td>NE</td>
<td>kg NO₃-eq./person/yr</td>
<td>Regional</td>
<td>119</td>
</tr>
<tr>
<td>Human Toxicity, soil</td>
<td>HTs</td>
<td>m³ soil/person/yr</td>
<td>Regional</td>
<td>157</td>
</tr>
<tr>
<td>Human Toxicity, water</td>
<td>HTw</td>
<td>m³ water/person/yr</td>
<td>Regional</td>
<td>179 000</td>
</tr>
<tr>
<td>Human Toxicity, air</td>
<td>HTa</td>
<td>m³ air/person/yr</td>
<td>Regional</td>
<td>2 090 000 000</td>
</tr>
<tr>
<td>Ecotoxicity, soil</td>
<td>ETs</td>
<td>m³ water/person/yr</td>
<td>Regional</td>
<td>964 000</td>
</tr>
<tr>
<td>Ecotoxicity, water chronic</td>
<td>ETwc</td>
<td>m³ water/person/yr</td>
<td>Regional</td>
<td>352 000</td>
</tr>
<tr>
<td>Spoiled Groundwater Resources</td>
<td>SGWR</td>
<td>m³ water/person/yr</td>
<td>Local</td>
<td>1200¹</td>
</tr>
</tbody>
</table>

¹ Calculated based on the Danish consumption of groundwater
Different from most other models available, EASEWASTE provides very detailed sub-models for the “end-of-waste” parts of the system: Landfilling, use-on-land, utilization of materials and recycling. The final disposal of the waste is the most crucial part of the waste management system and most of the things done up-stream, besides removing the waste, are done to avoid environmental impacts and loss of resources by the disposal of the waste. Accurate modeling of the disposal options is therefore important in assessing the overall performance of the waste management system including all treatment approaches. Unfortunately, the disposal part is also the most difficult part because of the long time horizons involved in leaching of pollutants and the lack of data representing these time periods.

EASEWASTE in its current research version has been applied in several studies including two full scale assessments of waste management in Danish municipalities (Herning, Århus), in comparison of technologies (landfill, incineration), in assessing material fraction management (paper, wood waste) and in comparison of models for specific applications (for example land-use of compost). These studies have provided new insight, some of which are being presented here regarding the modeling and data issues and the waste management.

The most important outcome of LCA-modeling of a waste management system may not be the final quantification of the resource consumption and potential environmental impacts, but the new quantitative understanding of the waste management system that the modeling induces. The fact that all flows of waste, residues etc. must be quantified in detail often provides unprecedented understanding of how the waste management system works. This can be obtained by many models, also in cases where the individual modules are rather simple. However, is the results expected to reflect changes in the system with respect to waste composition, diversion of waste, which affects the waste composition further downstream in the system, then detailed modules must be available representing the waste and the processes with an reasonable degree of reality.

MODELLING AND DATA ISSUES

**Process-specific versus in-put-specific emissions:** The process specific emissions are emissions that occur because the process occurs and are quantified as mass per tonne of waste. This means that waste with different compositions in materials or chemical substances all are causing the same emissions. This is reasonable for emissions that are controlled by the technology and operation of the process (e.g. NO\textsubscript{x} and dioxin from an incinerator), but not for emissions originating directly from substances in the waste (e.g. ammonium volatilization during composting or mercury in the flue gas from incineration). The latter should be estimated by transfer coefficients that provide a constant distribution of a substance in the in-coming waste to a specific out-flow, e.g. the off-gas of a composting plant. However, such linear transfer coefficients are only valid within a reasonable interval, which usually never is estimated. At the same time, as emission standards, in particular to air, become very strict, the emissions most likely become controlled by the process rather than by the content in the waste. EASEWASTE works with both types of emissions and in some technologies both may be involved simultaneously, for example, in the incineration module. This suggests that emissions from a process only can be estimated within a short range bracketing the conditions during which the original observations were obtained.
These issues are in particular important to realize in the context of leaching from waste, for example in terms of leachate from a landfill or drainage from incineration bottom ash used as base layer in a road. While the composition of the bottom ash can be estimated by EASEWASTE (as transfers of 39 substances from 48 material fractions), the leaching from the bottom ash is determined by the ash chemistry and the amount of water infiltrating (L/S ratio) and there is no direct link between leachate emission and bottom ash composition within a certain type of ash. Similar for the landfill: A higher content of lead in the waste does result in a higher content of lead in the leachate. However, the leaching will depend on the type of landfill and should be set differently for a mixed waste bioreactor landfill and a mineral waste landfill.

**Time issues:** Where waste is disposed of on land as a fertilizer, used as a soil amendment, landfilled or used in construction, the environmental emissions will take place over a long time period. For a mineral waste landfill, leaching may continue for thousands of years until it reaches an insignificant level. Usually data is available for only a few decades, and the longer the time horizon the more uncertain any estimates become. EASEWASTE allows for setting any time period that the user wishes and for which he can provide reasonable data. Within the time period emissions are accounted without any discounting. Only the cost estimation employs discounting. The distribution of leachate quantity and composition as well as methane yields (percent of methane potential as calculated from waste composition) are defined by the user. A time period of 100 years has been used in most of the EASEWASTE applications.

**Stored Toxicity:** Even if the time periods, as discussed above, are long, waste materials and substances are left in the waste at the end of the set time period. In a landfill, for example, the organic waste may be fully degraded or made inert, but the waste still contains significant amounts of materials and substances that can support leaching for long time. In order not to forget what is left in the waste after the time period in focus, EASEWASTE has introduced a new impact potential called stored toxicity. The model basically keeps account of how much is left of each toxic substance in the waste at the end of the period and ascribes each substance the characterization factor for ecotoxicity to water and to soil, 50% each. This may suggest that we assume that in the long run half of the toxic substances end up in the water compartment and the other half in the soil compartment. This is a somewhat arbitrary choice. This impact category is new and its weighting subject to the preference of the user.

**Spoiled Groundwater Resources:** Waste residuals used in construction (e.g. bottom ash in a road base) or landfilled waste release salts into groundwater if not all leachate is collected. These salts have no toxic characterization factors, but may still be able to spoil the groundwater from being used as a drinking water resource. We have introduced the impact category “Spoiled Groundwater Resources” to account for this. The amount of each salt ion leached is divided by the accepted concentration limit in groundwater, eventually drinking water, estimating how much ground water could be contaminated to the limit values by the leaching. This approach is consistent with the approach used in characterization of toxicity (dilution to a certain acceptable level, each substance counts individually). Figure 1 shows the result for 1 ton of waste being landfilled by 9 different landfill technologies. Even by modern landfill it is likely that 1 ton of waste can spoil groundwater in an amount of what 10 people (Danes) use within one year.
Local issues: In a product LCA, the production facilities are usually described in fair agreement with the actual facilities that are in focus. This may be a single manufacturing plant or a consortium of plants providing the various inputs. The end of the system, on the other hand, assessing the waste disposal of the product after use often uses general waste disposal data because the products may end up in many different countries with many different waste disposal systems exposing a lot of different environments. This is the basis for using general characterization factors for the potential impact categories. However, this may in the context of a waste LCA model not be fully satisfactory, since the model often addresses a specific system with a specific incinerator or landfill. EASEWASTE can handle the specific facility in terms of the emissions, but still general characterization factors for the impacts potentials are being used (as in any other models). This basically means that any emission is ascribed the same potential environmental impact, no matter how the local conditions are. This may suggest that approaches and methods for site-specific impact assessment should be developed for the waste LCA models.

Foreign recycling schemes: Many recyclables (paper, plastic, etc.) are traded on a world market, which makes it difficult to model the benefit of recycling of waste material fractions. The modeling requires that the environmental aspects of the upgrading and remanufacturing processes are quantified and that it can be assesses which type of virgin-based manufacturing the recyclables are substituting. Most of LCI data available from remanufacturing plants and virgin-based manufacturing plants originate from modern Western plants, which may not be fully representing the technologies involved world-wide. This issue may bias the assessment of the benefits of recycling waste. The bias can be to both sides.

Secondary waste streams: As waste management facilities become more and more regulated with respect to emissions to air and water, these emissions also become less important in the overall impact assessment. The regulation of the air and water emissions often involves introduction of some kind of cleaning technology that produces a secondary waste stream in terms of a dust, filter ash or treatment sludge. These secondary waste streams are often “removed”, “exported” or “forgotten” because they are hard to handle. They often become mixed
with many other small secondary waste streams and their fate is hard to assess. If these secondary waste streams are put into a landfill, assessment of methane potentials and leaching characteristics must be provided and such data are usually scarce. More attention should be given to these secondary streams in order to provide a full environmental assessment.

**INTERPRETATION**

**Waste management is environmentally sound:** One of the most important messages learned from using LCA models on waste management systems is that waste management systems actually are fairly sound in terms of recovering resource and restricting environmental emissions. Actually the waste management system may be saving environmental emission as was shown in the case of the City of Aarhus, Denmark (Figure 2). The high energy recovery (electricity and heat) from the waste incinerator and the energy savings from paper and glass recycling yielded a significant saving in global warming potential (CO₂ –fossil) assuming that the saved energy substituted for the production of energy at a traditional power plant based on coal and fossil fuels. The high human toxicity impact from the incinerator has since then been decreased by improved flue gas cleaning. The use of person-equivalence as the unit for potential impacts also provides some possibility to assess the over all magnitude of the impacts from waste management. A well designed and operated waste management system is not a major contributor to the environmental load.

**Impacts and indicators:** A full LCA modeling with EASEWASTE provides quantitative assessment of nine impact categories. Global warming potential always seems to be of importance, but also toxic categories may be important where emissions to air are significant. It should be remembered that while there is general consensus about how to quantify global warming aspects, the quantification of toxic categories is still in its infancy both method-wise and data-wise. Some kind of standardization of the toxic impact categories must be developed in the near future in order to gain confidence in these categories. However, it is also evident that it may be needed to select indicators that can represent the full LCA, since it may be very difficult to communicate the result of an assessment with 9 impact categories into a political process of decision making.

**Time issues and stored toxicity:** The accurate accounting of mass flows in the waste management system provided by the LCA modeling shows, as traditional emissions to air and water are being controlled by low guideline values, that the long term issues associated with landfills, waste residual in construction etc, are going to be the dark horse in the overall assessment. How much emphasis should be put on things that might happen in a hundred years, if global warming issues may have significant consequences within 50 years and should be addressed urgently? This suggest that decision making in waste management after introduction of LCA models may not become easier, but hopefully better addressing the real issues although these may appear increasingly complex.
Energy issues: If global warming potentials are in the political focus, LCA assessment of waste management systems will reveal that energy utilization in the waste management system is a key issue. This is as direct energy recovery substituting for fossil-fuel-based traditional energy production and indirectly by recycling of material fractions that by remanufacturing save energy compared to manufacturing based on virgin resources. If the energy content of the waste is efficiently utilized for substitution of fossil-fuel-based power and heat, then the energy spent in collecting and handling the waste is only of secondary importance. If the energy is not utilized then the energy spent in the collection is an important contribution to global warming.
**Convincing data:** An LCA assessment of a waste management system is uncertain with respect to both the system (definition and boundaries) and the data used. The system definition is usually the main responsibility of the modeler, since the result-users very often do not have the experience to judge the choices made. On the other hand, the result-users do not have confidence in the LCA results if the waste flows estimated as the basis for the assessment do not fit with the actual data for the system that the model represent. This suggest that an effort is put into modeling the actual flows as accurately as possible and that extensive, but realistic sensitivity analysis is performed to address the significance of parameters and data suffering from large uncertainty. In this way, the LCA modeling is accepted by the result-users and LCA model results can become a balanced platform for educated decision making.

**REFERENCES**


