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LIFE CYCLE IMPACT ASSESSMENT OF INTEGRATED SOLID WASTE MANAGEMENT SYSTEMS

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ABSTRACT
Life cycle impact assessment is the phase of an LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 1997). This study is intended as one basis for decisions regarding waste management energy policies. LCA is an iterative process, where information revealed during the course of the study may impose a revision of earlier steps.
Keywords: Solid Waste, Life Cycle Assessment, Management System.

1. INTRODUCTION

The problem of global climate change caused by increasing concentrations of carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases, determined many countries to make some changes in theirs energetic politic. One way of reducing emissions of greenhouse gases from the energy system is to reduce the use of fossil fuels. In many countries there is currently ongoing discussions on how to reduce the use of fossil fuels and increase the use of renewable fuels. Waste is sometimes regarded as a renewable fuel. Policies on waste management systems should therefore be considered together with policies on energy systems. Another way of reducing emissions of greenhouse gases is to reduce emissions of methane (CH_4) from degradation of organic materials in landfills. The investments must therefore be made in alternative management options for the waste that is currently being land filled. Before making such investments it is important to examine the consequences of different choices.

A waste hierarchy is often suggested and used in waste policy making. Different versions of the hierarchy exist but in most cases it suggests the following order: a) Reduce the amount of waste; b) Reuse; c) Recycle materials;d) Incinerate with heat recovery; e) Landfill.

2. SYSTEM BOUNDARIES

A key aspect of LCA is that the system should be modeled in such a manner so that inputs to and outputs from the system are followed from the "cradle to the grave". In LCAs of waste management systems, this is typically not done. Instead, the inputs are often solid waste as they appear, e.g. from households. This is still compatible with the LCA definition, if the same inflow appears in all systems which are to be compared. This is because those parts of the systems, which are identical in all systems that are compared, can be disregarded. The upstream system boundary have to be changed, if one of the systems to be compared produce more or less waste than the others. In this situation the system inputs are no longer identical, and in principle the system boundary should be moved and upstream activities be included, at least those parts which differ between different systems.

In LCAs of waste management systems, products from recycling are not followed to the "grave" and neither are the products, which are replaced by the products from recycling. This is compatible with the LCA definition, if the products are "identical" in all systems which are compared. Identical does not mean that they have to be exactly identical in all aspects. It is enough if they are providing a comparable function to the user, and if they have the same environmental impacts.

3. LANDFILLS AS CARBON SINKS

When carbon flows in landfills are modeled, a distinction is often made between biotic (from renewable sources) and non-biotic carbon (from fossil sources). Common practice is to disregard biotic CO_2-emissions. This can be motivated from different perspectives. One includes an expansion of the system boundary to include also the uptake of the CO_2 in the growing tree. This expansion is often done as a thought experiment rather than an actual modeling. Another perspective can be the assumption that when biotic resources are harvested, new resources are planted which will take up an equivalent amount of CO_2. Again this modeling is normally not done explicitly. Yet another perspective is the assumption that if the biotic resources, e.g. trees, had not been harvested, they would have been left in the forest and degraded there. This degradation can however be quite slow, and the time frame has to be extended to several centuries before all biotic materials have been degraded.

The practice to disregard biotic CO_2-emissions can lead to erroneous results. When incinerated, nearly 100 % of the carbon is emitted as CO_2. However, in the inventory, this emission is often disregarded as noted above. If the product is landfilled, approximately 70 % of the material is expected to be degraded and emitted during a short time period, mainly as CO_2 and CH_4 Again the emitted CO_2 is normally disregarded, although the CH_4 emissions are noted. During the surveyable time period, 30 % of the carbon is expected to be trapped in the landfill. There is thus a difference between the landfilling and the incineration alternatives in this respect, in the incineration case all carbon is emitted, whereas in the landfilling case some of the carbon is trapped. This difference is however not noted, since the CO_2-emissions are disregarded and this is in principle a mistake. Additionally, the biological carbon emitted as CH4 in the landfilling case is noted and will discredit this option. It could be argued that a part of the global warming potential, corresponding to the potential of the same amount of biological carbon in CO2, should be subtracted from the landfilling inventory.

4. LIFE CYCLE IMPACT ASSESSMENT OF INTEGRATED SOLID WASTE MANAGEMENT SYSTEMS

Life cycle impact assessment is the phase of an LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 1997). In an LCA it will normally not be known where and when all the emissions take place. This is one of the reasons why LCA cannot predict actual impacts but is restricted to analysing potential impacts. When analysing emissions from landfills the situation is enforced since the emissions will occur in a future situation. The emissions cannot be measured but only predicted. A consequence of the predictions is that it is potential emissions rather than actual emissions that can be included in the LCA for landfilling processes. This can make the impact assessment more difficult because there are increased problems modelling background concentrations and other aspects which may be of importance for the impact assessment. There are however, other situations in an LCA where emissions occur on different time scales, e.g. in LCAs on building materials. The standard solution to this problem is to treat all emissions as if they occur at the same moment. If this is also assumed for landfilling processes, methods that are being used for LCIA in general can also be used for waste management systems.

The definition of LCA states that the assessment should include the complete life cycle, and there is no restriction in time. This suggests that all emissions should be included, regardless of when they occur. However, if one would like to put a lesser emphasis on future impacts there are two possible solutions:

1) A cut-off after a certain time period. If this approach is used, emissions after a certain time period, and impacts associated with them are completely disregarded. The implicit assumption is that impacts after the chosen time period are of no importance. This is consistent with a view that future generations are of no importance.

2) A discounting is made. The purpose of discounting is to discriminate against the future The choice of the discount rate is an ethical and ideological issue both in relation to the question of how future generations are valued and in relation to expected economic growth.

Discounting is currently not used in LCA. A cut-off is used in the approaches where emissions from landfills are only considered for a certain time period, and the remaining waste is described as inert if considered at all. When using that type of approach, an ethical valuation is implicitly made to place no importance on impact affecting future generations. It is important to realize that when deciding on which time period(s) to consider in an inventory analysis, an ethical valuation is in practice being made.

5. METHODOLOGICAL CHOICES

5.1 Functional unit

It is important to define correctly the function unit. We considered, for example same kind of fractions of municipal solid waste which are combustible and recyclable or compostable, collected during one year.

We want to analyse the effects of different choices concerning waste management. The results are intended to be used for strategic decisions including decisions on new investments and policies. The time frame is long (decades) because decisions made today or in the coming years on for example energy systems and waste treatment facilities will have effects several decades into the future. (Please note that "long time-frames" can have very different meanings. When discussing the goal of the study a long time frame means decades. When discussing landfills, decades is a short time frame. A long time frame for landfills means time periods substantially longer than decades.)

5.2 Waste materials, treatment methods

The waste materials are fractions of household waste: food waste, newspaper, corrugated board, mixed cardboard, polyethylene, polypropylene, polystyrene, poly(vinyl chloride) and polyethylene terephtalate.

The treatment methods considered are incineration (of all fractions), landfilling (of all fractions), recycling (of all fractions except food waste), anaerobic digestion (of food waste) and composting (of food waste). The biogas produced from anaerobic digestion is either used as fuel replacing diesel or for production of heat and electricity. For the whole system, recycling is combined with either anaerobic digestion or composting of the food waste. Source separation is assumed as a part of the recycling strategies. Also incineration may be combined with source separation.

The study is an LCA and this implies that ideally all inflows should be traced back to the system boundary between the environment and the technosphere, and all outflows should be traced to the point where emissions leave the technosphere. There are several exceptions to these rules:

- The waste is taken as the input to the system and not followed upstream. This is compatible with the LCA definition since equal amounts of waste of the same composition are treated in all systems.
- Materials which are assumed to replace each other, e.g. recycled plastics replacing plastics produced from virgin materials are not followed downstream. This is compatible with the LCA definition if the properties are identical. This is a problem for some paper fractions where the recycled material is somewhat heavier than the material produced from virgin materials.
- In the case of forestry, the wood and biofuels are taken as inputs to the technosphere.
- Additives and auxiliary materials are included whenever data has been available. In some cases however, upstream data on additives and auxiliary materials has not been available.
- Landfilling of waste will be in principle included. This is the case for all wastes being inflows in this study, ashes from incineration of waste, and sludge from wastewater treatment of leachates from landfilling of waste and drainage water from composting.

- There are of course different types of data gaps, inflows and outflows that are unknown to us and therefore not included.
- Capital equipment is in general not included in the study.

6. CONCLUSIONS

When useful products are produced from the waste treatment systems we have used the system expansion approach for avoiding the open-loop allocation. Open-loop recycling takes place when a product is recycled after its use, into another product. The systems we are studying therefore have only one functional unit, but several functions which are not leaving the system. For each waste treatment method there is one or several functions which are avoided.

We can use in the study two time-perspectives:
"The surveyable time period", which is defined as the time period it takes to reach a pseudo steady state in the landfill. The surveyable time period should correspond to approximately one century. In this case the time period is defined by the processes in the landfill. For municipal solid waste landfills, the surveyable time period is defined as the time it takes to reach the later part of the methane phase when gas production is diminishing.

The choice of the avoided function can have a decisive influence on the results; it will be briefly described also here:
- Heat from solid waste incineration and incineration of landfill gas and biogas from anaerobic digestion is assumed to replace heat produced from other sources which are varied. In the base scenario biofuels are used, and in two alternative scenarios, natural gas is assumed.
- Electricity produced from incineration of landfill gas and biogas is assumed to replace electricity from coal-fired power plants as a marginal source of electricity.
- Fuel produced from biogas is assumed to replace diesel fuel.
- Recycled paper is assumed to replace paper materials of similar qualities made from virgin materials.
- Recycled plastics are in the base scenario assumed to replace plastics of the same kind produced from virgin raw materials. In one scenario however, recycled mixed plastic waste is assumed to replace impregnated wood used in palisades.
- Residues from anaerobic digestion and composting are replacing artificial fertilisers with similar contents of nitrogen and phosphorous.

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