Sustainable solid waste management needs to be environmentally effective, to reduce overall environmental burdens, economically affordable for all sectors of the community served and socially acceptable. Integrated Waste Management (IWM) takes an overall approach to this, involves the use of a range of different treatment options and deals with the entire waste stream. Life Cycle Inventory (LCI) can successfully be applied to assess the environmental burdens associated with IWM systems. The technique is now past the “theoretical tool” stage and it is important to look at the practical experience to date and identify how the tool has been used, what it contributes, where it is particularly helpful and, just as importantly, where it is not helpful.

Introduction

Sustainability can be viewed as a triangle, with one of the three elements (environmental, economic and social) at each of the angles (see Figure 1). In simple terms, sustainability is about balancing these three elements. A stable balance requires all three elements to be considered equally. Therefore for solid waste management to be “sustainable” it needs to be environmentally effective, economically affordable and socially acceptable.

**Environmental effectiveness:** requires that the overall environmental burdens of managing waste are reduced, both in terms of consumption of resources (including energy) and the production of emissions to air, water and land.

**Economic affordability:** this requires that the cost of waste management systems are acceptable to all sectors of the community served, including householders, commerce, industry, institutions and government. The costs of waste management have always been closely and carefully monitored, as systems that are not financially viable often quickly become expensive failures with significant negative impacts on both the environment and the local population.

**Social acceptability:** requires that the waste management system meets the needs of the local community, and reflects the values and priorities of that society. This third aspect of sustainability is the area that although understood to be of increasing importance with respect to waste management, it has received considerably less attention than either the economic or the environmental issues.

![Sustainability triangle](image-url)
A key question is how can we assess the overall environmental effectiveness and economic affordability of waste management systems, so that we can plan more sustainable waste management for the future? This paper shows how the technique of Life Cycle Assessment (LCA), and the tool of Life Cycle Inventory (LCI) in particular, are already being used to answer this question.

Along with the overall need for sustainable waste management, it is also becoming increasingly clear that no one single treatment method can handle all materials in municipal solid waste (MSW) in an environmentally efficient way. Following a suitable collection system, a range of treatment options will be required, including materials recovery, biological treatment (composting and/or biogasification), thermal treatment (burning of refuse-derived fuel (RDF), packaging-derived fuel (PDF) and/or mass-burn incineration) and landfilling (see Figure 2). Together these can form an Integrated Waste Management (IWM) system.

![Figure 2. Elements of an Integrated Waste Management system](image)

End of the road for the waste management hierarchy?
Past decisions on waste management strategy and the structure of waste management systems have relied either explicitly, or implicitly, on the "waste management hierarchy". This has varied in its exact form, but usually gives the following order of preference: waste reduction; re-use; materials recycling; composting; incineration with energy recovery; incineration without energy recovery; landfilling. Such use of a priority list for the various waste management options has serious limitations, however.
• The hierarchy has little scientific or technical basis. There is no scientific reason, for example, why materials recycling should always be preferred to energy recovery.
• The hierarchy is of little use when a combination of options is used, as in an IWM system. In an IWM system, the hierarchy cannot predict, for example, whether composting combined with incineration of the residues would be preferable to materials recycling plus landfilling of residues. What is needed is an overall assessment of the whole system, which the hierarchy cannot provide.
• The hierarchy does not address costs. Therefore it cannot help assess the economic affordability of waste systems.

The limitations of the waste management hierarchy are becoming increasingly apparent, especially in relation to IWM systems. The UK Waste Strategy, *Making Waste Work*, for example, suggests that although useful as "a mental checklist", "the waste hierarchy will not always indicate the most sustainable waste management option for particular waste streams..."\(^1\). Similarly, a study comparing different solid waste management options in the European Union concluded: “the social cost-benefit analysis of MSW management systems in the European Union seems to support the conclusion that the “waste hierarchy” is too simplistic, and that blind adherence to its tenets can lead to welfare losses.”\(^3\)

In essence what is needed is less waste to deal with in the first instance, and then an IWM system to handle the waste that is still produced in an environmentally sustainable, economically affordable and socially acceptable way. Rather than rely on the waste hierarchy, the environmental management tool of Life Cycle Inventory can be used to help reach this objective.

**Life Cycle Inventory - One Tool in the Toolbox**

LCI and LCA are useful tools, since they take an overall approach, but it has to be remembered that they do not cover all dimensions that must be addressed. Because it does not consider concentrations of emissions in the environment, nor exposure to emissions, LCA (even including an impact assessment) cannot assess human or environmental safety. For this the separate tool of risk assessment is needed. Nor can it assess whether legal requirements are being met: other tools are needed to ensure compliance with relevant environmental legislation, and to ensure that social concerns are addressed\(^4\). The usefulness of LCI in waste management is in assessing environmental efficiency. Given that all the individual operations, such as composting, incineration, landfilling etc. are safe, LCI will help determine the optimal integrated combination of these options that minimises energy and raw material consumption, and the generation of air and water emissions and final residual solid wastes.
It also needs to be stressed that an LCI or an LCA will not actually make any decisions about the “best” waste management strategy. A LCI for solid waste management will provide a list of energy consumption, and emissions to air, water and land, over the whole life cycle, and will also predict the amounts of useful products that arise from waste, such as compost, secondary materials and useful energy (Figure 3). The best system for any region will depend on local needs and priorities, such as the need to reduce landfill requirements, or the desire to reduce water emissions or air emissions. Thus, LCI is a decision-supporting tool, not a decision-making tool. The selection of the best IWM system for any region will still require a decision to be made, but LCI can provide additional, overall environmental information for use in the decision-making process.

**Using LCI for Waste Management**

Computer models for conducting LCIs for waste management systems are already available for use in Europe\(^5\), America\(^7\), Canada\(^11\) and elsewhere. They provide a first attempt at using LCI for this purpose. One of the benefits of this work has been to identify where reliable data are not available, and where further research is needed.

A wide range of different groups have started to use such LCI tools for waste management, for a variety of reasons. Regional and local waste planners and consultants have used existing LCI tools to help plan waste management strategies for many regions, including Gloucestershire\(^8\) in the UK, Barcelona\(^9\) and Pamplona\(^10\) in Spain, and London, Ontario, in Canada\(^11\). LCI is also being used by waste management companies to assess the environmental attributes of future contract tenders, and by academics teaching environmental management courses in Europe and North America.
The benefit of using a tool like LCI is that it provides flexibility by allowing assessment of the optimal waste management strategy for a given region, on a case-by-case basis, taking into account these factors. LCI provides an alternative to a rigid hierarchy of options; it should not be used to simply reinvent a different hierarchy. Hence LCI is best used as a case-by-case tool, rather than to try to identify a single solution for a whole country or continent. The role of policy should be to set the desired outcomes from waste management, such as energy conservation, or reduction of global warming potential. LCI can then be used to help reach these outcomes. Hierarchies, in contrast, try to specify the means, rather than the desired end results.

**What do the users say?**
The benefits of using LCI in a case-by-case way can be seen from looking at the examples where it has already been used. To date LCI models have been used as:

- Benchmarking tools: to assess the current environmental profile of a waste management system.
- Comparative planning tools: to allow a series of "What if...?" scenarios to be investigated and compared.
- Communication tools: to provide information on alternatives that can be shared with all interested stakeholders, including citizens.
- Sources of data: to provide comprehensive and coherent data on all aspects of waste management.

There are many cases where LCI has been used to “inform” waste management decisions. The ultimate test of the value of LCI as a decision support tool, however, is to look whether it has influenced decisions. The answer is yes. In Barcelona, the newly proposed waste strategy for the region was developed using an LCI study using the model published by White *et al.*\(^5\). In Pamplona, the option of composting is now under consideration following an LCI study\(^10\). London, Ontario have approved an expanded recycling system based on public acceptability and environmental benefits but at a higher cost to the municipality. The use of the LCI model (within a decision making framework) ensured that elected officials made their decisions based upon both environmental and economic data.

**Where to from here?**
The earliest LCI models for solid waste management were no more than a first attempt to apply the technique to this new field. Talking to the users of such tools, it is clear that many improvements can be made. In particular, LCI tools for Integrated Waste Management need to be:

- Easy to use. They should be accessible to waste planners and managers, not just the domain of LCA experts or computer boffins. Only if they are easy to use will full use be made of their potential to run creative “what if ..?” scenarios. Input from user groups will be essential to ensure the tools meet the needs of waste planners, managers and others.
- Easy to understand and communicate to others. Endless tables of data do not communicate well. The Canadian model, for example, has provided an interesting way to dimension differences between options, by equating them to electricity consumption by homes, emissions from cars etc.\(^11\).
- Flexible. Users need to be able to customise the models so that they fit their specific circumstances.
• Credible. If LCI results are going to be used as the basis for discussion between the many and varied stakeholders in waste management decisions, the tool needs to be credible. The methodology and assumptions must be transparent, and the basic data relevant and reliable. Having endorsement from the UK Environment Agency or the US EPA may help in some way to establish the credibility of models.

It is through the experiences of waste planners and managers with the tool of LCI that its full value will be understood, and the best ways to include it in the decision-making process determined. A few case studies have started to appear in the literature - some are referenced above - but clearly more are needed. We are currently working to collect and publish the experience of users, to try to facilitate this process. Together with user-friendly, credible, reliable and flexible models, this will help fully explore the potential of this environmental management tool in Integrated Waste Management.

Acknowledgement

References