Life Cycle Thinking

Introduction

The use of energy, and the use of water are two examples of environmental considerations where we need to consider the whole of a product's life. As with waste, and issues about replacement solders, such concerns can be analysed particularly effectively using two inter-related techniques:

- The product **life cost**. In the past this has been primarily a way of assessing 'cost of ownership' throughout life, which totals capital cost, running costs, servicing and maintenance, and eventually disposal. The concept can however be extended to cover the product's impact on the environment and/or the energy involved in the activities, remembering that all purchased materials will have consumed energy at all stages from the extraction of raw materials to final manufacture.

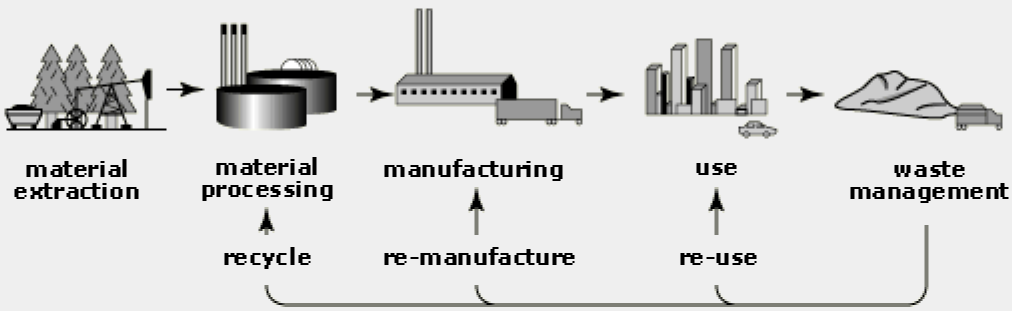
- The product **life cycle approach**, which looks at the total interrelationship from raw materials, through manufacture to the product, throughout its use, and from disposal through recycling to create new raw material.

The need for life-cycle thinking

We need to think of the whole of the life-cycle of a product, because products may have totally different environmental impacts during different stages of their cycle. For example, some materials may have an adverse environmental consequence when extracted or processed, but be relatively benign in use and easy to recycle. Aluminium is such a material.

On the other hand, a printer or battery-powered product will create the bulk of its environmental impact during use, because of the consumption of consumables.

Figure 1: The life cycle of a product

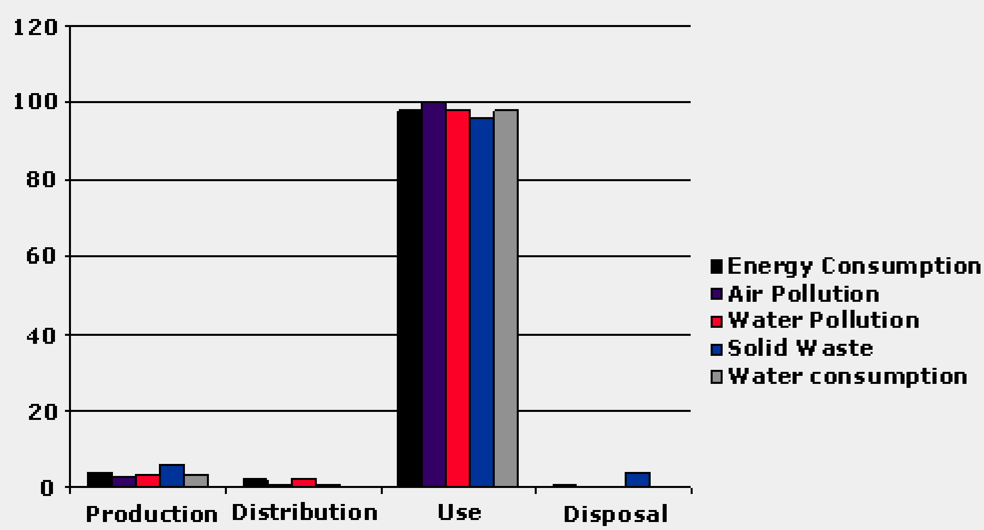


The product life cycle in Figure 1 is shown in five distinct phases, all of which interact with the environment. For most products, the period of use is far longer than the other periods, and there may also be periods of storage and non-use between the stages shown. Usually, but not always, these stages will be environmentally benign.

Figure 1 also shows, as feedback loops, the potential for recycling, remanufacturing, and reuse. We will be saying more about these later, but it is worth making the obvious point that reuse is the strategy that potentially has the lowest environmental impact, merely based on the fact that this involves fewer processes, and each stage absorbs energy and has an environmental impact.

Figure 2 shows a life-cycle assessment of a washing machine, in terms of the energy and water used, of the contribution to pollution of air and water, and of solid waste. As you might expect, most of the environmental impact is during use. However, you might have predicted that most of the solid waste impact would be the two stages of delivery (when the packaging is removed and disposed of) and eventual end-of-life disposal. Whilst the solid waste levels are indeed significantly higher than other contributors at these stages, in fact they total less than 15% of the solid waste produced by the washing machine. Strange? Just think of the many packets of washing powder and other consumables that are thrown out during the machine's life. This illustrates how careful we must be to consider every aspect of use, and to draw the 'system boundary' broadly enough to cover this.

Figure 2: LCA of a washing machine, source: Andrew Sweatman



Life-cycle assessment provides use with information on environmental impact. An extension of the analysis also allows us:

- to take account of the fact that products have different environmental impacts – furniture may deplete rainforest timber; appliances have a major impact on energy consumption
- to determine where the greatest benefit will be and so to prioritise the environmental aspects of a product that need to be improved

Unfortunately, environmental design guidelines can often be conflicting; remember that the increased reflow temperatures involved in using lead-free materials will substantially increase the energy requirements of the process. In order to determine the best environmental option, we need a formal process.

Formal Life Cycle Analysis

In stating that the system considered needs to be sufficiently broad to take in all the elements of interest, we have already implied that Life Cycle Analysis takes a system view of the world. Let's start by looking at the formal process of Life Cycle Analysis, which you will find described in the two codes of practice that follow.

Two definitions of Life Cycle Assessment

"Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal."

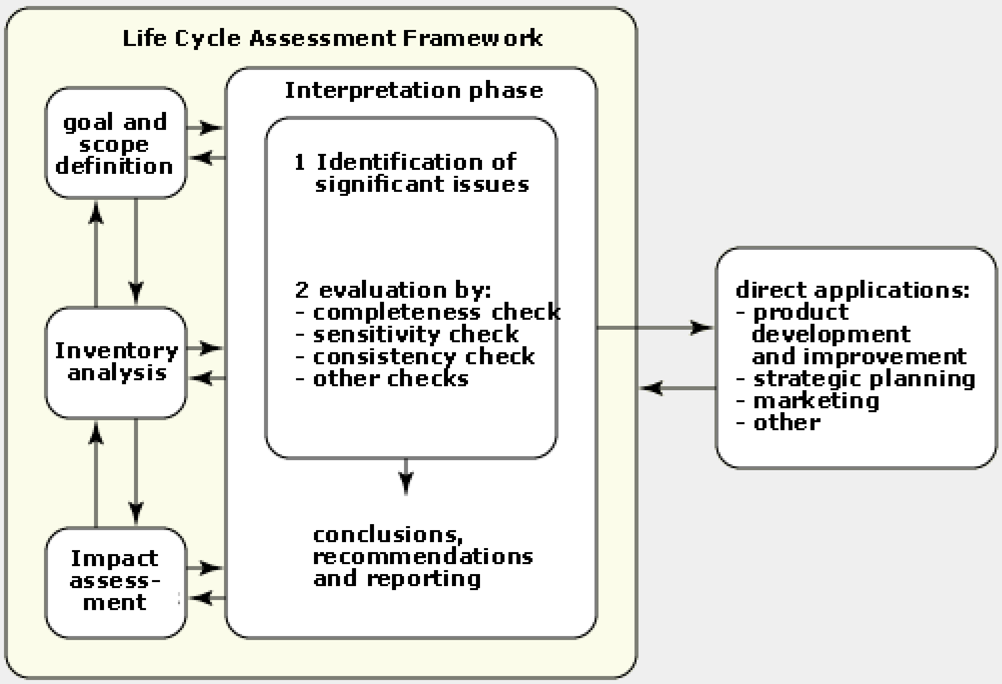
***Guidelines for Life-Cycle Assessment: A Code of Practice* (1993)**
SETAC (Society of Environmental Toxicology and Chemistry)

> “LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:
>
> - compiling an inventory of relevant inputs and outputs of a product system;
> - evaluating the potential environmental impacts associated with those inputs and outputs;
> - interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.
>
> “LCA studies the environmental aspects and potential impacts throughout the product’s life (i.e. cradle to grave) from raw materials acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences.”
>
> ***ISO 14040***

You will see that Life Cycle Analysis is both holistic and seeks to *quantify* the impact. A system view, it looks at all inputs to the system, and all outputs, at all stages during the entire life cycle. It also categorises environmental impacts in terms of the use of resources, the impact on human health, and the consequences for the wider world – the so called ‘ecological consequences’.

The framework within which life cycle assessment is carried out is shown in Figure 3. Two main activities are preceded by a vitally important planning phase and followed by extended interpretation, which will normally involve checking the results both against the initial goals and for self-consistency.

Figure 3: The Life Cycle Assessment framework



There are two main activities in an LCA:

- The **inventory analysis** step, which describes the emissions that occur and the materials and resources used during the life of a product
- The **impact assessment** step, which looks at the impacts of emissions and use of resources and raw materials on the environment.

The first stage in inventory analysis is to define the product assembly. Typically this will be broken down into a number of different levels, first into subassemblies, and then into the materials and processes. At the end, we have a set of life-cycle inventory (LCI) results, known as an ‘inventory table’. This is a list of all the raw material extractions and emissions that occur in the production of the assembly and the materials and processes that link to it.

The next stage is the conversion of these inventory items into impact categories. This simplifies the information, converting many separate entries into a smaller number of environmental impacts. This step is referred to as ‘characterisation’, and the output is an analysis by subassembly of how the impact is generated.

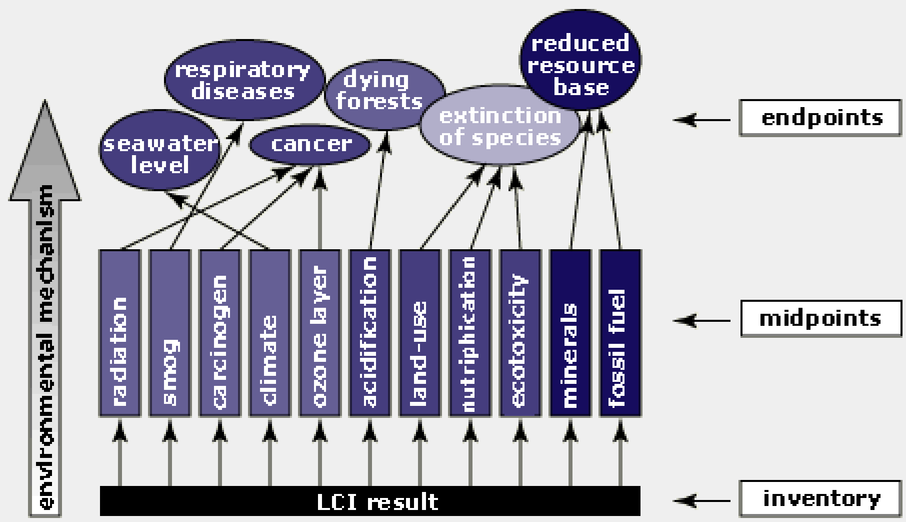
After characterisation, all impact category indicators have been scaled to 100%, so it is not easy to see which parts of the product have the highest overall environmental impact. For a more representative picture, we need to scale the measurements so that they can be related to each other, a procedure called ‘normalisation’. This reveals which effects are large, and which are small in relative terms, though says nothing about the relative *importance* of these effects.

Even at this early stage, we have made a number of assumptions about the environmental impact of the items on the life-cycle inventory. With so many environmental factors to consider, and different views on their relative importance, it is not surprising that a number of different models are used to translate information from inventory to impact category indicator and through to normalised indicator result.

Eco-indicator 1999 is a commonly-used model, but just one of a number that will yield somewhat different results. However, using one model consistently to compare different potential products, coupled with some sensitivity analysis and a liberal use of common sense, will indicate with reasonable certainly which of the alternative designs being considered is the most environmentally friendly.

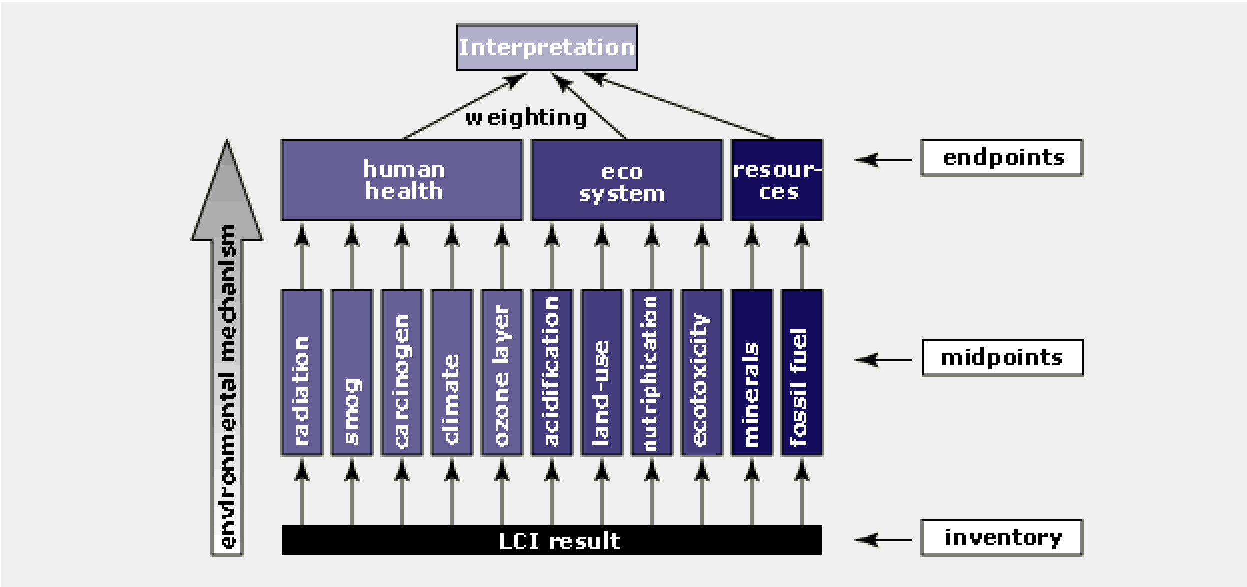
In Figure 4, we have a general overview of the structure of an impact assessment method. The life-cycle inventory results are related to the so-called ‘endpoints’, which are issues of environmental concern, by ‘midpoints’, which reflect the mechanism by which the environmental effect takes place. Note that ISO 14040 does not stipulate which endpoints should be selected, but obviously these must be chosen carefully to fit the product under review, and then related to the impact categories.

Figure 4: Structure of an impact assessment method



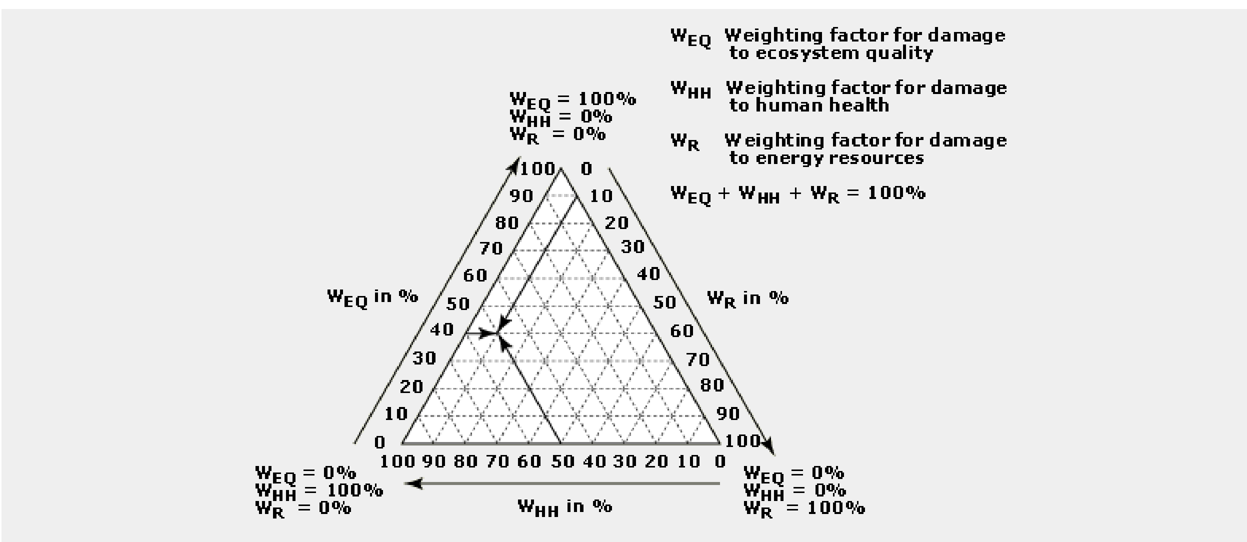
As shown in Figure 5, this model can be simplified by choosing a consistent set of endpoints, and relating indicators to these, so that the effects of indicators that relate to the same endpoint can simply be added together. By weighting the different endpoints, it then becomes possible to calculate a single environmental score, which is a shorthand way of indicating the environmental impact of a product over its life.

Figure 5: Goedkoop and Spriensma methodology for impact assessment



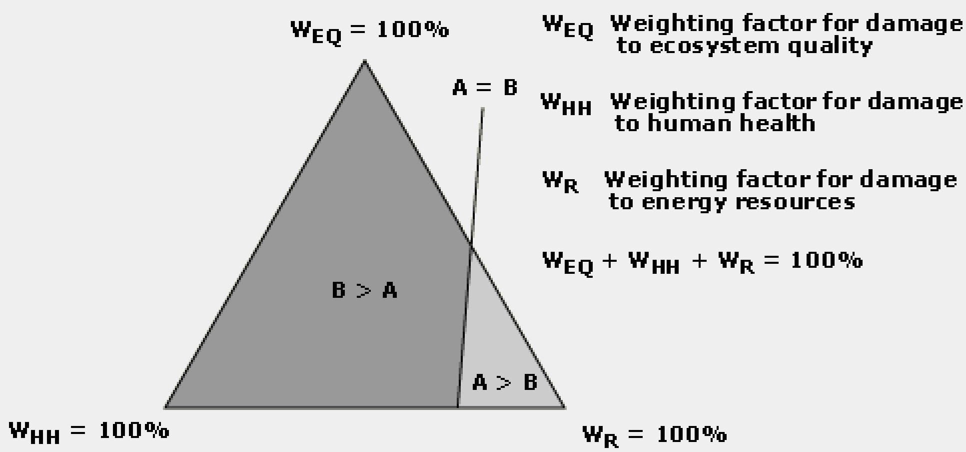
The Eco-indicator 99 methodology takes as its three standard endpoints damage to human health, to ecosystems and to natural resources. The key problem of course is what relative rating to place on the three! LCA has a formal way for viewing this, as demonstrated by the ‘mixing triangle’ in Figure 6. You will be familiar from other uses of this technique that the coordinates at any point in the triangle add up to 100%.

Figure 6: The ‘mixing triangle’



As an extension of this idea, as shown in Figure 7, one can draw a boundary on the triangle where the area on one side of the line is environmentally less damaging that the other side.

Figure 7: The 'line of indifference'



So far we have looked at the process by which a total impact score for each subassembly, material and process in the assembly can be calculated. There are, however, many uncertainties about this score:

- There are inaccuracies and variables in the generic models used when creating the inventory table, and when converting inventory items into impact categories

- Major uncertainty arises from assumptions built into the specific models about the usage of the product and its eventual disposal

- The total impact score may be distorted by the weightings chosen.

This last can at least be tackled by standardisation. In the Eco-indicator 99 model, the weightings between these three categories default to

40:40:20, a division based on the opinion of an extensive panel of experts from many sectors.

Using LCA

LCA became popular in the early 1990s, initially because it was thought to be a good tool to support environmental claims that could be directly used in marketing. However, although the communication of LCA results is important, a survey by Rubik and Frankel showed that LCA is most often used for internal purposes such as product improvement, support for strategic choices, and benchmarking. One of the reasons that LCA is less used than it might be in marketing is that it is necessary to apply weighting factors in order to generate the kinds of single score that are easiest to use for marketing. However, because weighting is inherently subjective, ISO 14043 specifically disallows its use for public comparisons.

Rubik and Frankel's study also showed that the most important pitfall is the lack of a clear definition of the purpose and application of LCA. This is very much in line with the importance placed in SETAC's Code of Practice on the first stage of planning. The five stages into which this splits the LCA are:

	Planning:	Statement of objectives Definition of the product and its alternatives Choice of system boundaries Choice of environmental parameters Choice of aggregation and evaluation method Strategy for data collection

	Screening:	Preliminary execution of the LCA Adjustment of plan
	Data collection and data treatment:	Measurements; interviews; literature search; theoretical calculations; database search; qualified guessing Computation of the inventory table
	Evaluation:	Classification of the inventory table into impact categories Aggregation within the category (characterization) Normalization Weighting of different categories (valuation)
	Improvement assessment:	Sensitivity analysis Improvement priority and feasibility assessment

Note that SETAC have introduced a screening stage after planning, in order to check the goal definition. At first sight, this Code of Practice differs from ISO 14043, but is in practice just a different formulation of the advice that one should review the initial results of Life Cycle Assessment against the objectives, in order to be able to plan the rest of the project.

Looking at LCA tools, such as the SimaPro software provided by PRé Consultants, is beyond the scope of this module, but you should be aware that, as with any modelling technique, the outcomes are highly dependent on the quality of the inputs. Fortunately, there are a number of recognised sources of information that can be used to make these analyses more meaningful, and at least easier to compare with each other. It is the availability of such standard information, and its integration within the simulation, that makes this type of software particularly helpful.

The need for awareness

Life Cycle Analysis is far from being a trivial exercise. Conceptually simple, projects of this nature frequently run away with resource, yet yield results that are difficult to interpret. It is partly for this reason that use of the formal technique is generally restricted to larger companies and left to specialists, and its use confined principally to comparing alternative product strategies. However, some awareness of the technique will help you to ask the right questions, and to carry out a preliminary comparison of significant design alternatives. Think of the ‘cradle to grave’ costs whenever you are researching new materials or methods, and be particularly aware of the way in which the environmental cost of ownership of products can be influenced by the running costs in energy and consumables.

Life Cycle Cost Assessment (LCCA)

Another holistic approach that concentrates more on the effect on the company than on the environment is life-cycle cost assessment (LCCA). This is one of the techniques promoted by the EU’s EEE Directive, which aims to improve the overall impact of electrical and electronic equipment on the environment “thus providing an efficient use of resources and a high level environmental protection compatible with sustainable development”.

Source : http://www.ami.ac.uk/courses/topics/0109_lct/index.html