USING LCI RESULTS

Introduction

The interpretation of LCI data is far from standardised and some of the interpretations and conclusions that are drawn from them are highly questionable. The purpose of this short note is to try and identify what is justifiable and what is mere speculation.

Background

Life cycle assessment really started in the early 1970's. At that time there was concern about two main environmental problems: conservation of resources, mainly fossil fuels, and thermal pollution of the atmosphere.[1]

It is important to remember that this was the time when there was an upheaval in the US packaging market. Returnable containers were fighting the newly introduced non-returnables in the beverage market, aluminium was challenging tinplate, cans were challenging glass bottles and the plastics bottle was just beginning to make its appearance. Claims and counter-claims were made by the commercial organisations involved with these products. The consumer could make little sense of the claims and the environmental lobby was suspicious not only of the data being used to substantiate the claims but also to the conclusions that were being drawn from them. To a lesser extent these concerns were beginning to be voiced in Europe.

Preliminary studies, mainly by academics, showed that many of the claims being made were false, mainly because the proponents of a particular scheme were focussing only on those parts of the system that were favourable to themselves. It soon became clear that the only way to compare different packaging systems satisfactorily was to look at the full life cycle from cradle to grave so that both the advantages and the disadvantages of any system were incorporated into the final results. This was the beginning of LCA's, although they were not called that at the time.

One important feature of these early studies was that the emphasis was on energy and resources so that the interpretation of the results was usually unambiguous. Although during the 1980's, emission data were gradually incorporated into the calculations because the calculation method was identical to that for other parameters, there was little demand for the results.

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[1] This was not the greenhouse effect but the release into the atmosphere of increasing amounts of heat.

The involvement of SETAC

In 1990, SETAC (The Society of Environmental Toxicology and Chemistry) organised two conferences; one in Vermont, USA and the other in Leiden in The Netherlands. It is important to remember that although the attendees at these conferences had an interest in the results of cradle to grave studies, few had any practical experience of carrying them out. The Vermont conference introduced the term *Life Cycle Assessment* for the first time.

These conferences gave rise to two important results; the LCA was divided into different phases and the emission data were given much more prominence than hitherto.

The first of these was summarised in the form of a simple diagram as shown in Figure 1.

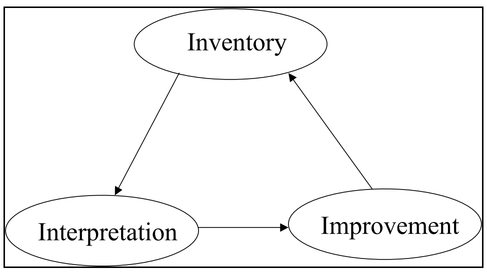

Figure 1. The SETAC triangle

SETAC recognised three distinct phases; inventory, interpretation and improvement. The inventory phase provided the quantitative description of the system as it currently existed and the interpretation phase related these quantitative data to observable environmental effects. The improvement phase suggested changes that could be made to improve the system and these were tested by a revised inventory to see if the expected changes did indeed occur and to identify any unwanted side effects that might accidentally be introduced. This cyclic procedure essentially summarised what had been going on for the previous 20 years.

The simple idea of Figure 1 has since been subjected to much discussion and 'improvement'. Like all good ideas, its clarity owed much to its simplicity. Unfortunately, once committees start to pick at the bones of the idea, its shortcoming become evident and modifications increase the complexity of the idea until it becomes almost unintelligible.

Because SETAC was a toxicological organisation it is perhaps not surprising that emission data were given greater prominence. Unfortunately, this sowed the seeds of the present day problems because many of those present wanted to interpret LCA emission data in the same way as they interpreted plant data, forgetting that LCA systems were global in extent.

The involvement of ISO

After 1990, SETAC held a number of other conferences to examine different aspects of LCA's but their impact was considerably less than the 1990 conferences. In 1993 SETAC organised a conference in Portugal which generated a voluntary code of practice. This eventually led to the setting up of the ISO workgroups under TC207 which led to the production of the ISO series 1404* series of standards.

In many ways the ISO exercise was somewhat premature since LCA's are still in a formative stage and the whole field is too broad for a simple standard – it's rather like trying to write a standard on *nuclear physics*.

Essentially, as far as interpretation is concerned, the relevant workgroup recognised that although there was some firm scientific groundwork on greenhouse gases and acid rain, there was still too much uncertainty surrounding other effects for any hard guidelines to be issued.

Why did LCA's start?

Before getting into the detail of interpretation problems, it is well to remind ourselves of why LCA work ever started. The whole field was not dreamt up by some under-employed academics seeking to fill their time. It arose because there was a need for hard, quantitative, physical information describing the performance of extended industrial systems. This physical information was not available from existing organisations but was needed to put alongside the volumes of political, economic and social information so that more balanced judgements could be made in the environmental field. It was, and still is, essentially a form of process analysis and the goals were initially modest. Some proponents of LCA's seem to forget this and regard it as an all-embracing tool that will solve all environmental problems.

Interpretation problems

There seem to be four main problems associated with the interpretation and use of LCA data:

1. Do LCA's provide a comprehensive picture of the environmental impact of an extended industrial system?

2. Do the aggregated data resulting from an LCA study have any physical significance?

3. How can the results of an LCI be related to observable environmental effects?

4. Can LCA data be combined in some way to produce an overall judgement of the environmental impact of a system?

Do LCA's provide a comprehensive picture?

The inventory stage of an LCA provides quantitative information on:

Energy consumption
Feedstock consumption
Raw materials consumption
Emissions to air
Emissions to water
Solid waste generation

These data are aggregated over the whole cradle to grave system. Furthermore, the accuracy and completeness of the information is dependent on the accuracy and completeness of the raw data supplied by the companies making up the extended system. Any missing or inaccurate data will be reflected in the final results.

If we assume that companies are not deliberately falsifying data, then the data returns are based on the data that are held for their processes. This will change with time. For example, only a few years ago, no one held data on carbon dioxide emissions nor were they included in LCI calculations. Nowadays, any LCI, which did not report carbon dioxide, would be regarded as incomplete. There is no means of knowing whether the data that are currently requested for inclusion in LCI calculations will be regarded as deficient in the future.

It is important to note that LCI's are concerned with quantitative physical data. Therefore any physical effects that cannot be quantified will not be included in the calculations. Thus effects such as biodiversity, for which there is no recognised measurement, will be absent from the calculations.

It follows therefore, that LCA's do not represent a complete picture of the environmental impact of a system. They represent a picture of those aspects that can be quantified. Any judgements that are based on the interpretation of LCI data must bear in mind this limitation and, if necessary, obtain additional environmental information from other sources.

Do LCI data have any physical meaning?

The data from individual plants are objective and possess physical meaning. The problems arise when data from a number of different plants in different locations are aggregated.

It is important to recognise that the extended systems used in LCA's are global in extent. For example, within the petrochemical industry, crude oil is obtained from the North Sea, the Middle East, South America, Africa and South East Asia. Similarly, apart from indigenous production, the coal used in thermal electricity generation in Europe comes from North America, Australia, South East Asia, China and South America. Thus when data are aggregated in LCI calculations, they refer to the total global burden.

Thus aggregated data, which possess global significance, do have some meaning. Consumption of resources (fossil fuels and raw materials), which draws from a global pool, obviously qualify. Similarly, emissions which do not degrade quickly and which spread over the whole globe (e.g. carbon dioxide and ozone depleting compounds) will also qualify as meaningful.

In contrast, aggregated localised burdens cannot sensibly be regarded as meaningful. For example, it has been argued that noise should be included in LCA's. What does an aggregated noise value mean? If the Australians decided to mine bauxite using an atom bomb, it would be heard in Australia but it would certainly not be heard in Europe or the USA. Similarly, chemical oxygen demand (COD) as a measure of water pollution is a localised parameter as would be most forms of solid waste. Aggregating such parameters is mathematically possible but the resulting total is physically meaningless.

One way of viewing these results is by plotting a diagram such as that shown in Figure 2. This considers two effects: whether the data are meaningful or meaningless and whether the data are objective or subjective. In LCI's the original raw data from the participating plants have usually been subjected to simple mathematical procedures to adjust units of measurement and normalise with respect to unit output from unit operations before aggregation. As a consequence, the final results can usually be regarded as objective as the original raw data. However, as discussed above, these aggregated data have a variable meaning as shown in Figure 2.

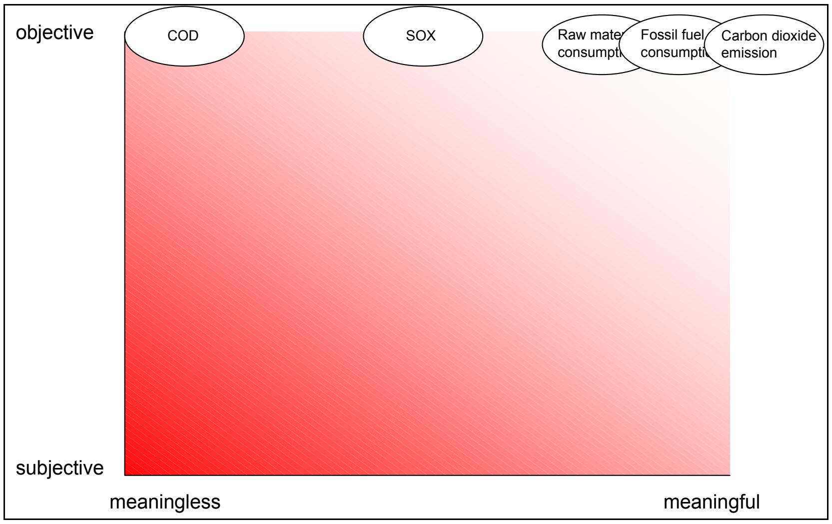

Figure2. Simple plot to illustrate how meaningful aggregated LCI data should be regarded

How can LCI data be related to environmental effects?

Environmental effects can be divided into three groups:

Global
Regional
Local

Thus any environmental effect that is global in extent can be addressed directly by the results from an LCI. Typical of these effects will be greenhouse gases, ozone depleting emissions and depletion of resources.

Regional effects, such as acid rain, can be addressed by using the detail within an LCI. For example, suppose that a simplified LCI system consists of 10 unit operations each taking place in the countries shown in Figure 3. In order to calculate the full LCI it would be necessary to evaluate the data for each of these unit operations before they are aggregated into the final LCI data set. As noted above, the full LCI would be applicable to global effects. However, from the detail of the LCI, a sub-set consisting only of those operations occurring in the Netherlands could be selected and a restricted average calculated for them in order to address regional problems.

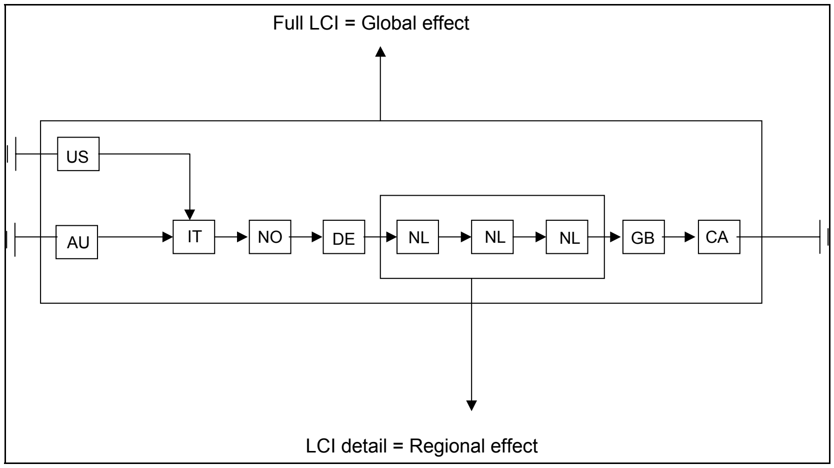

Figure 3. Hypothetical LCI system with unit operations taking place in different countries.

In contrast, it is doubtful if LCI data can offer anything new compared with the usual monitoring of unit operations that would be carried out for compliance with local pollution regulations. Furthermore, most of the pollution data used in the construction of LCI's is based on the regular monitoring exercises carried out by plants as part of their normal compliance exercises.

It is also important to recognise that the use of LCI data as a means of describing pollution effects can be very misleading. This is especially true, if the data are treated as if they originate from a single point source. For example, suppose that an LCI shows a total burden of 100 mg of some toxic material. If this burden were really emitted by a single point source then it could represent a serious toxic hazard. However, if this total burden arises from the sum of the emission of 1 mg by 100 plants spread over the surface of the earth, then there could well be no hazard.

Thus for global effects, the aggregated results obtained directly for an LCI are applicable. The analyst should therefore select the parameters that relate to the specific problem and ignore the rest of the data set. For example, suppose that the aim is to examine the greenhouse gas contribution of the system. The parameters of interest would all come from the air emissions results and so data on energy and feedstock consumption, raw materials consumption, water emissions and solid waste would be discarded. Even within the group of air emissions results, only those such as CO_2, CH_4, etc., which relate directly to the greenhouse effect, would be selected; the remainder would be discarded.

The aggregated results from an LCI, which can run to several hundred parameters, are directly applicable to global effects. They should, however, be treated as a data set from which the appropriate parameters are selected to address a specific problem; the remaining parameters are ignored. It follows from this that different groups of parameters will be selected in order to address different environmental problems.

For regional problems, the globally aggregated data sets are not appropriate. From the detail of the LCI, a sub-set can however be selected to address specific problems. For example, if the aim is to examine the incidence of acid rain in Scandinavia, one of the main components is the emission of SOX in the United Kingdom and Poland. Such emissions could be extracted from the overall detail of the LCI and this provides the appropriate data to address this problem. A similar approach can be adopted to examine solid waste problems and regional water pollution problems.

For local problems it is doubtful if the globally aggregated data from an LCI offers anything of significance – especially as most of the data are already available without carrying out an LCI. Anyone using such globally aggregated data to address such localised problems would need to make a very strong case justifying such an approach.

Can LCI data be combined?

Two types of combinations are currently in use:

1. Combination of data that address a specific problem
2. Combination of data to produce an environmental index.

These need to be examined separately because they are quite different in character.

Data combination for specific problems

This often known as characterisation and valuation and is best illustrated by a simple example.

Suppose that we are interested in the contribution that a system makes to greenhouse gases. The LCI data provides information on the total emission of gases such as CO_2, N_2O, CH_4, etc. which all contribute to radiative forcing. However, it is not possible to simply add together the quantities of these different gases for two reasons. First, it is mathematically incorrect because the units are different – kg CO_2 cannot be added to kg CH_4. Secondly, the effect of CH_4 is different to the effect of CO_2 and these differences need to be taken into account. Fortunately, data are available on the relative influence of the different gases that contribute to the greenhouse effect.[2] The relative effects of each gas are expressed in multiples of the effect of CO_2, setting CO_2 itself to 1. The quantities of each of the gases contributing to the greenhouse effect can therefore be converted into carbon dioxide equivalents (sometimes referred to as global warming potential). They now all have the same units and their relative effects have been taken into account. Consequently they can be summed to give an overall carbon dioxide equivalent for the system.

This type of combination, which is based on sound scientific grounds, is acceptable but it is important to recognise that it addresses a single specific problem. Because this procedure involves manipulating the data in order to produce the carbon dioxide equivalents and because the IPCC data is subject to regular revisions as better information is discovered, there is inevitably an element of subjectivity introduced into the final result. On the meaning diagram this can be represented as a shift as shown in Figure 4.

There are however some instances where the conversions are erroneous. For example, it is often proposed that raw materials resources should be referred to the rate of depletion of reserves. This attractive idea suffers one major drawback: reserves of any raw material change with time. The reason for this was neatly summarised by McKelvey.[3] He proposed that a graph should be plotted of economic feasibility against geological assuredness as shown in Figure 5.

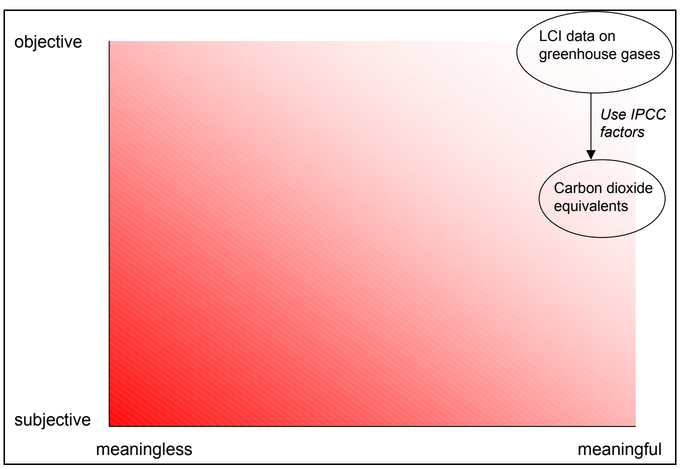

Figure 4. Increasing subjectivity introduced by calculating carbon dioxide equivalents

[2] *Houghton, J.T., Jenkins, G.J. & Ephraums, J.J. (eds). Climate Change – The IPCC Scientific Assessment. ISBN 0-521-40360-X. Cambridge University Press. 1990. Revised data published in 1995.*
[3] *McKelvey, V.E. Approaches to the mineral supply problem. Technology Review, pp 13-23, March/April 1974.*

From this it is clear that the reserves of any raw material (the shaded portion of Figure 5) are determined by a deposit of the material being identified and being economic to extract. Thus as the price of a raw material increases or as further supplies are discovered, the reserves will increase. Similarly as price falls, then reserves fall. Thus, using reserves as a base against which to measure depletion of raw materials is extremely uncertain and time dependent.

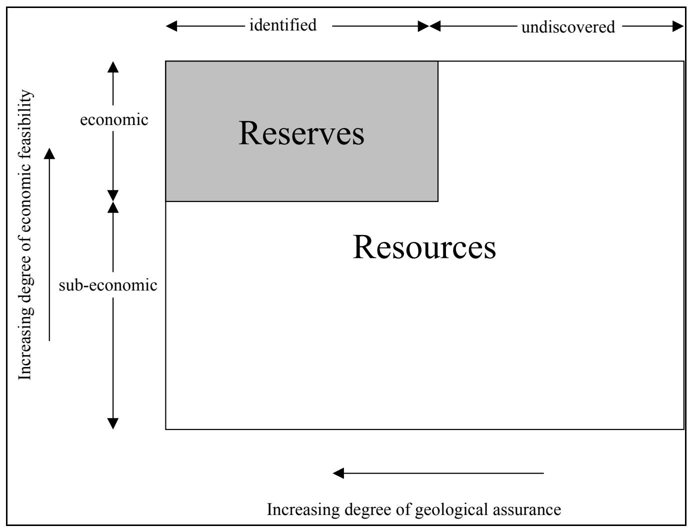

Figure 5: The McKelvey diagram.

On the meaning diagram, the use of this procedure means that not only do the data become more subjective but they also lose some meaning because of the possibility that the normalising factors are wrong (see Figure 6)

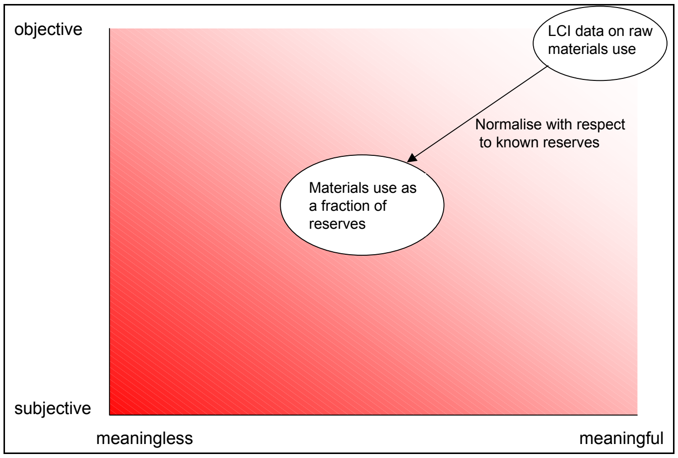

Figure 6
Change in meaning when raw material consumption
is normalised with respect to reserves

In all cases when data are acceptably aggregated, as for example by calculating carbon dioxide equivalents, it has to be recognised that there is a loss of data. If the aim of carrying out an LCA is to find ways of improving the system, then the overall carbon dioxide equivalent is of little help. Only by examining the contributions to this overall total is it possible to identify the major contributors. Thus although selective aggregation of data is useful as a means of summarising the effects of a system, they are of little use is process design.

Data combination for eco-indices

An eco-index is a single parameter that is intended to summarise the environmental quality of a system. This index can be on a scale of 1 to 10 or, as in the case of eco-labels, on a scale of 'good' or 'bad'. Two factors have pushed towards the development of such indices. First there was a feeling that the number of parameters generated by LCI's was so large as to be unmanageable, especially when used in applications such as the design process. Secondly, there was the understandable desire to have some simple form of summarising all of this information so that the intelligent layperson could get some idea of the overall environmental implication of the system.

There are then three stages needed to produce any form of eco-index as shown schematically in Figure 7. First the raw data collected from the various companies within the system are combined in the inventory calculations. Secondly, in the classification and valuation stages, the inventory data are grouped together and summed in an appropriate manner so that each of the grouped data sets describe some environmental facet of the system. Finally, these grouped data sets are multiplied by some weighting factor that is intended to reflect the relative importance of the effects and finally they are summed to give an overall index.

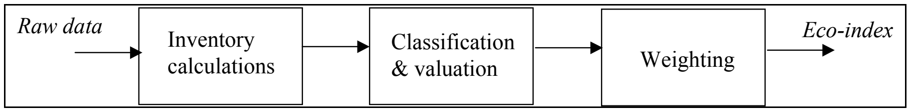

Figure 7.
Stages in the production of an eco-index.

The limitations of the inventory stage and the classification and valuation stage have already been discussed. But the problems in these stages are as nothing compared to the errors introduced in the weighting stage. Assigning these weighting factors implies that it is possible to make sensible judgements about the relative importance of effects such as global warming, acid rain and fossil fuel use.

It is critically important to recognise that there is no scientific way in which such value judgements can be made. It does not matter whether they are determined by a panel of 'experts' or related to some social, political or economic considerations. ***The weighting factors are totally subjective***. As a consequence, the eco-index is also subjective. Furthermore, any decisions based on the use of using eco-indices are also subjective.

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7 September, 2001