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LIFE-CYCLE ASSESSMENT AS A TOOL AND PHILOSOPHY

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Abstract

Current knowledge provides a conflicting basis for quantifying sustainability, as central issues such as resource use and resultant impact remain unresolved. To this end, well-established practices auditing and environmental assessment systems have evolved to become encompassed under a collective methodology of Life Cycle Assessment (LCA).

This paper discusses the framework of LCA and its use as a systems tool for the quantification and qualification of environmental impacts. Specific emphasis is placed on PVC-U joinery profiles and the identification of embodied energy impact. Moreover the paper questions the philosophy behind the adoption of LCA values by governmental organisations in order to promote a utopian hierarchy of sustainability.

Keywords: Life-cycle assessment, PVC-U, Embodied Energy, joinery profiles

Introduction

The realisation of the vulnerability of the earth's eco-systems has led to the design of new initiatives that aim to both assess and address an activity's impact upon the environment. Current knowledge nevertheless provides a conflicting basis for quantifying sustainability, as central issues such as resource use and resultant impact remain largely unresolved.

The general consensus remains that society must keep its activities within the Earth's true "carrying capacity" [UNEP 1991]. To this end well-established practices such as energy audits, risk assessments, and mass balance exercises have evolved to become encompassed under a collective methodology of Life Cycle Assessment (LCA), which may be defined as:

"the compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life-cycle" [ISO 1997].

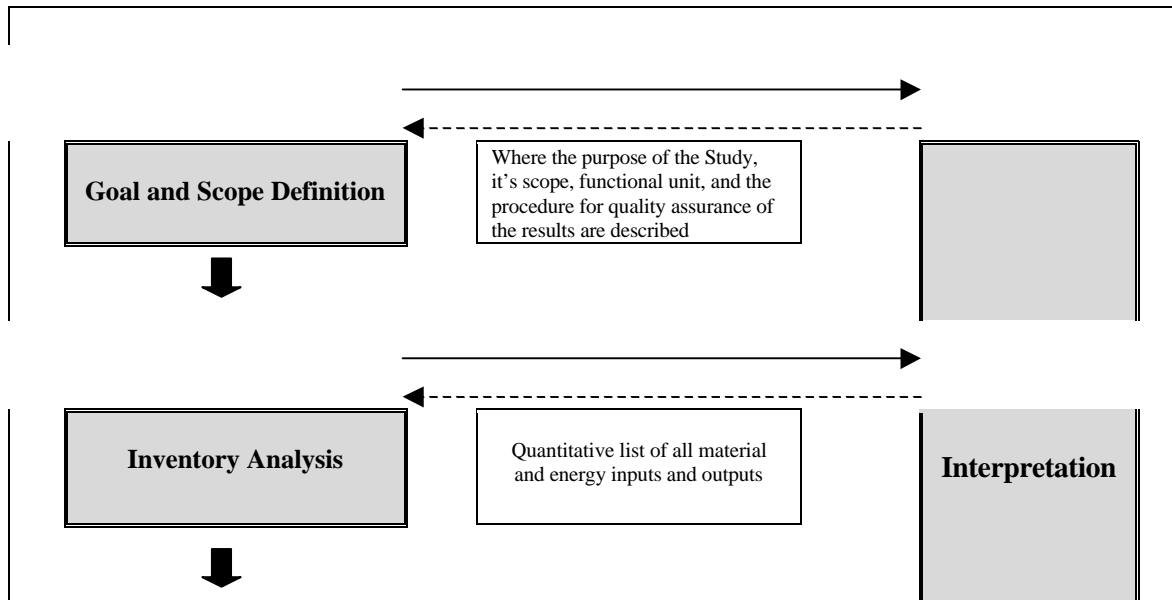
As a concept LCA targets the entire cradle to grave activities of a product or process; from the extraction and processing of raw materials to transportation and use, in addition to reviewing the issue of material re-use and final disposal. LCA therefore identifies the system processes and potential environmental burdens throughout a product's life-cycle.

Moreover as a philosophy, LCA is employed in order to attain the environmental goals of replacing ecologically damaging systems, reducing reliance on finite resources and minimising material waste. This has arguably resulted in LCA being perceived as a

panacea for all environmental ills and is increasingly considered as a key tool for the justification and implementation governmental policies on sustainability [EC 2000: DETR 2000].

LCA as a tool

In seeking to achieve the utopian ideal of placing all activities in a hierarchy of sustainability, the application and assessment of LCA must be carried out in a consistent manner. However the complex interactions experienced within all life-cycles often preclude detailed comparative analysis of differing functions, be they products or processes. As the very nature of industrial or organic system processes impede the formulation of rigid methodological rules, each activity often requires incompatible criteria of assessment. In order to address the inherent weaknesses experienced in the quantification and qualification of environmental data, a standardised framework is required. The identification of four key phases, as illustrated in Figure One, now forms the framework for international LCA design.



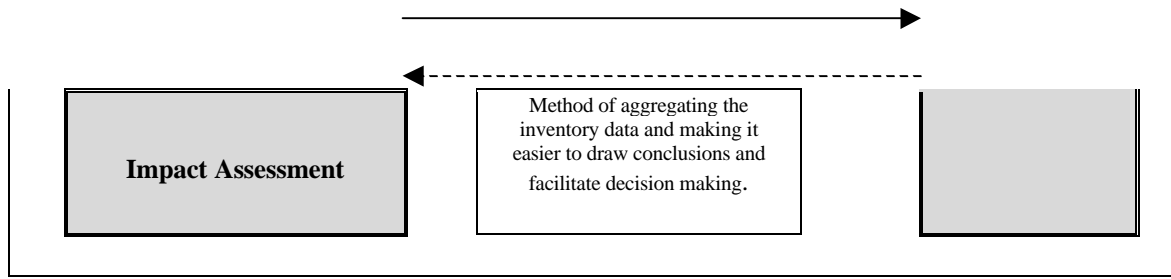


Figure 1: LCA framework

Each phase of the framework provides, in principle, a reasoned approach for assessing a function's life-cycle burden and enable the logical sequencing of the environmental parameters of a proposed study.

Based on SETAC [1993], the model aids comparison between similar processes, which in turn enhances the ultimate goal of establishing a hierarchy of environmental burden. From this broad framework, international agreement, in the form of ISO 14000 series, now underpin the nature and content of global LCA.

The ISO documentation [ISO 14040; 14041; 14043; 14062] reflect the rapid evolution of LCA, with the key to a well-reasoned study being the adoption of a methodology that displays clarity, transparency and credibility. Clarity in its *Goal and Scope*, transparency in the presentation of *Inventory Analysis* data and credibility in the areas of investigation and review. Indeed as one primary objective is to enable a practitioner to gain an understanding of the applicability, validity and limitations of a study, the three "covenants" are to become an integral element for all life-cycle assessments.

Material, energy and emissions flows of even the most basic functions however impede comprehensive evaluation. Allocation of the resultant burdens and pursuing a comparative study between dissimilar systems further compound the collation and analysis of data. The sheer magnitude of all potential inputs and resultant outputs would result in a LCA of any given function becoming unmanageable.

A study should nevertheless initially address all aspects and review the interaction of the flows identified. Only then may limits be set in order to exclude primary, secondary or tertiary sub-system processes as appropriate. System boundaries - what is and is not to be included in the study - may then be set accordingly. All data generated within the

boundary may then be related to a single unit for comparison; a Functional unit (FU). The FU becomes the quantified performance of the life-cycle investigated. It is therefore the FU and not the function to which all data will be allocated and analysed. Figure Two illustrates this consideration.

Figure Two highlights the sub-system processes associated with the formation use and enduse of PVC-U joinery profiles. Sub-systems analysed, in this exemplar, concern joinery profiles only. Data acquisition therefore focuses on the sub-systems within the System Boundary and each sub-system is analysed in three distinct phases, as identified in Figure Three.

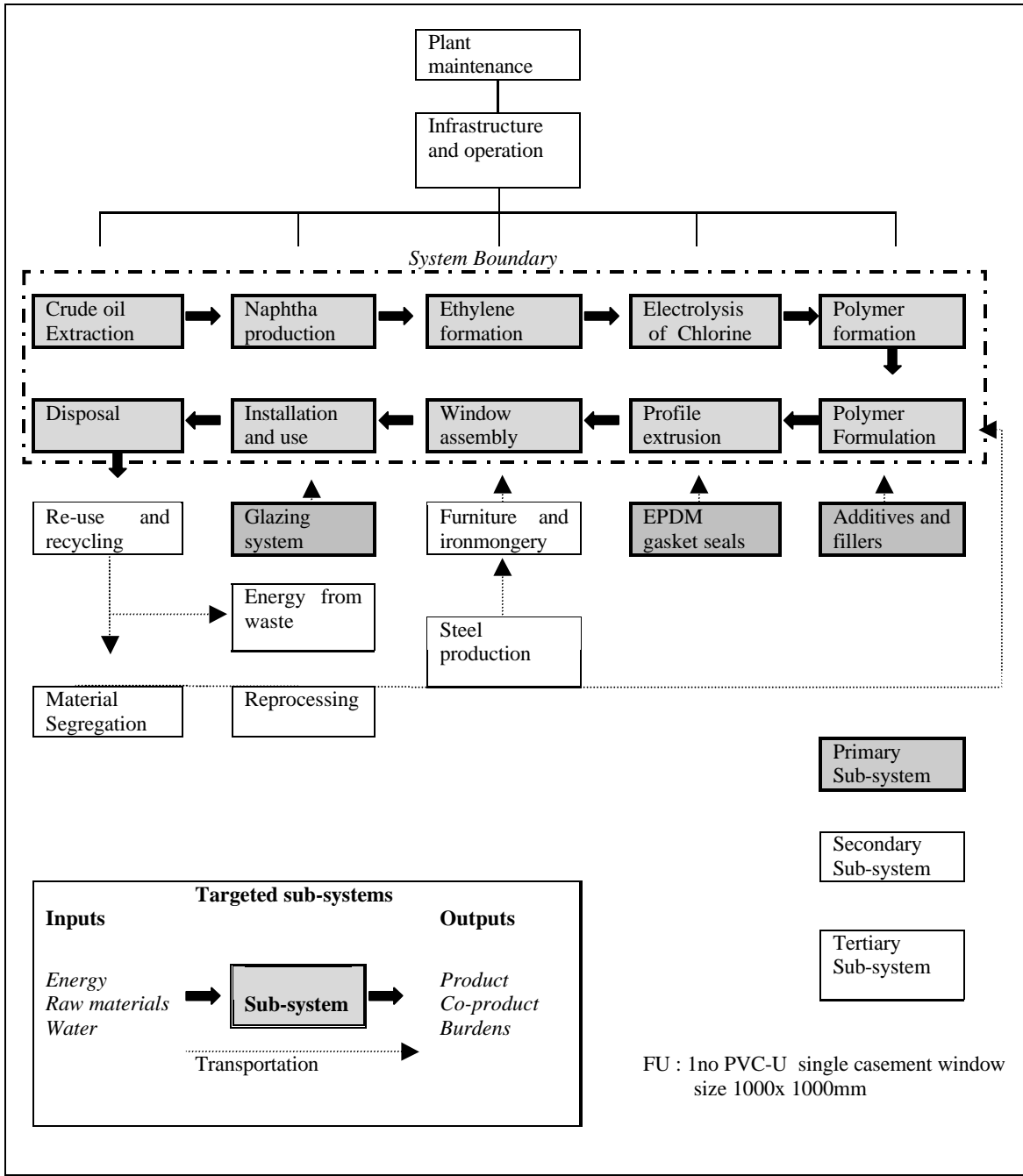


Figure 2: Sub-system processes associated with the formation and use of PVC-U joinery framing system

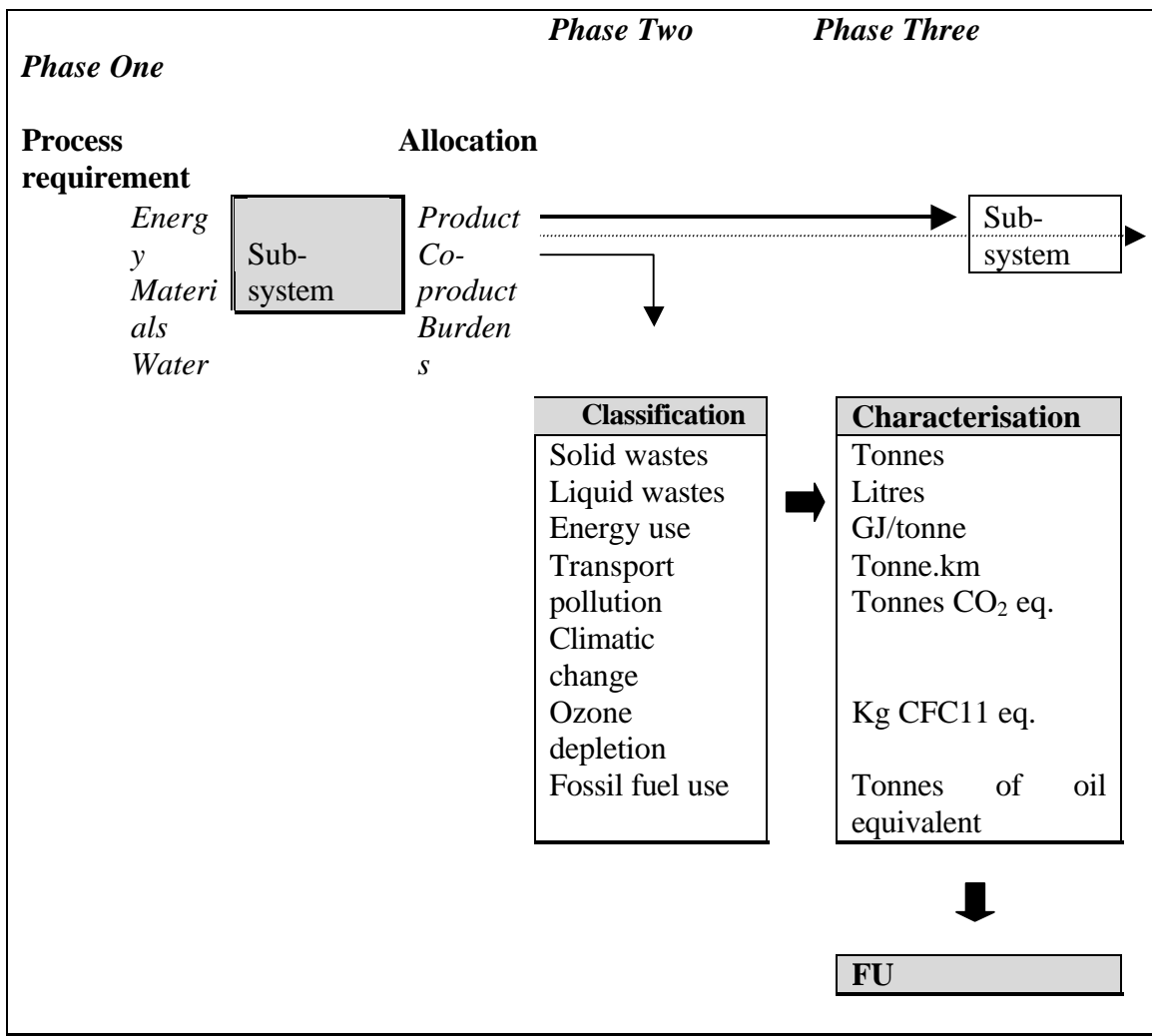


Figure 3: Process allocation, classification and characterisation.

Phase One, Process requirement, apportions the inputs. That is the material and energy feedstocks required to produce the targeted output from the sub-system are quantified against a standard unit of measurement. Examples being the mass of product or, in the case of joinery profiles, a metre run. *Allocation*, the second phase, enables the resultant solid, liquid and airborne emissions (burdens) attributed to the sub-system to be partitioned against all procurable outputs. The revised sub-system burden may then be quantified against the FU accordingly.

A number of environmental classifications are employed in assessing burdens. These categories may range from the specific assessment of a single emission, for example carbon dioxide, to the grouping of several interventions in order to ascertain a known environmental impact such as climate change. Each classification will display a unit of measurement, the characterisation of which enables the impact of differing FU's to be compared. Phase three of an LCA, *Inventory Analysis*, thus characterises the unit of

assessment for each burden investigated and, following the mass balancing of all sub-systems in order to identify cumulative life-cycle impact, the FU as a whole. A completed *Inventory Analysis* consequently determines the life-cycle “footprint” of a specific FU in relation to the sub-systems targeted.

Appraisal of differing FU's may only be undertaken provided the second LCA follow the same *Goal and Scope* methodology. The inclusion or exclusion of any sub-system, for example re-use and recycling sub-system processes, will return a significantly different "eco-footprint" from that of landfill disposal and therefore invalidate comparative environmental assessment.

It is this consideration that often negate the merits of previous LCA studies, whilst comparative analyses of environmentally emotive or commercially sensitive functions also impede true identification of impact and burden. This consideration is non-more apparent when reviewing LCA against the application and use of PVC.

LCA studies of PVC-U joinery

LCA studies into the formation of the basic PVC powder record values in the range of 34 [Vestolit 1996] to 69 MJ/kg [APME 1994]. Each study is of accepted merit yet emphasises the variances that may be attributed to industrial processes and the boundaries of a study. These disparate values are also determined against one sub-system element the total life-cycle of any PVC product.

As process requirement and allocation of burden compound assessment, each sub-system of any PVC product is subject to considerable variations that include the introduction of stabilisers and additives, their impact on service-life and enduse options currently available. As a consequence, expansion of the system boundaries to include additional processes exacerbates assessment. In turn the geographical scope and its impact on energy mix and conversion efficiency, transportation burden and service life further complicates the comparative review of a function's life-cycle impact. Thus recent studies into the formation of unplasticised PVC (PVC-U) joinery record embodied energy (*EE*) values ranging from 42 [DETR 2001] to 71 MJ/kg [IKP 1998], a discrepancy of almost 90 per cent.

Research conducted by the University of Brighton [Flanagan 2001; 2002] investigated the interactions between polymer formation, use and re-use. The study adopted methodology based on accepted ISO 14041 [1997] practices. The completed study concerned the analysis of the systems relating to a distinct life-cycle and examined the impacts against a specific FU in the form of a single PVC-U casement window, dimension size being 1000x 1000mm with a polymer content of 14.323 kg. The resultant eco-profile is therefore process specific, quantifying all sub-systems associated with the formation and enduse of PVC-U window framing.

Primary data collection focused on profile extrusion, assembly operations, and the re-use of virgin waste [Flanagan 2000]. The principal impacts associated with installation and

use of the material as a joinery system were also identified. Mass balancing and thermodynamic techniques underpinned sensitivity analysis of the secondary data utilised for polymer formation sub-systems.

The completed inventory analysis of the eco-profile provides a reasoned assessment of the process operations associated with the formation, assembly, use and enduse of PVC-U joinery profiles. The eco-profile cumulative total of 83.27 MJ/kg is comparable with published LCA values which range from 71.55 MJ/kg [IKP 1998] to 138 MJ/kg [Richter 1995]. The energy consumption of each sub-system in isolation and the cumulative impact within the complete life-cycle is identified in Table One.

Sub-system Process	Eco-profile Site operations	Eco-profile FU	Richter [1996]	IKP [1998]
Raw materials	39.94	39.94	----	----
Polymer Formation	16.73	16.73	48.20	----
Profile extrusion	6.59	4.12	3 to 5	----
Assembly	4.73	3.07	----	----
Installation and use	0.00	0.00	----	----
Landfill	0.04	0.04	----	----
Transportation	9.58	9.58	----	16
Cumulative impact	87.52 MJ/kg	83.27 MJ/kg	138.85 MJ/kg	71.55 MJ/kg
Cumulative CO ₂	2866 g/kg	2220 g/kg	----	2881 g/kg

Table 1: Eco-profile embodied energy (MJ/kg).

The *EE* value for mean energy use of *Eco-profile site operations* (87.52 MJ/kg) equates within eight per cent of the averaged value of the two studies. Process specific operations of *Eco-profile FU* (83.27 MJ/kg) are within 12 per cent of the mean impact. It is nevertheless incorrect to consider that this not dissimilar statistical correlation conclusively validates the eco-profile as each study displays both differing functional units and methodological assumptions.

The Richter study [1996] for example evaluated the life-cycle impacts of varying window profile materials using European data sets. The FU was determined to have a polymer weight of 17.5 kg, with dimensions being identified as 2.6m² only. Process specific data characterise PVC-U material formation and extrusion to utilise 48.2 MJ/kg and 3 to 5 MJ/kg respectively. The University of Stuttgart study [IKP 1998] analysed the life-cycle impacts of differing German window systems. The PVC-U window size was 1.23 x 1.48m, with a PVC-U composition weight of 14.577 kg.

The consideration of compatible LCA data remains the greatest weakness of existing studies as unless analysis is like for like the judgement cannot be valid [Ayres 1995].

Krähling [1999] corroborates the limitations of comparative review between LCA studies as, on appraising eight life-cycle assessments concerning PVC-U, concluded that the significance of results could only be evaluated against general objectives. Further, as only two of the studies [EMPA 1996; IKP 1999] attained the general requirements of ISO 14040 [1997] the lack of symmetry in system boundaries and methodological framework further negated comparison. Research by Hunkeler et al [2000] concurs the limitations in comparative analysis between environmental assessments and provides a statistical accuracy variation to be in the range of ± 30 -40 per cent. Comparison of any life-cycle inventory data should thus remain indicative and not prescriptive.

As a consequence a completed study provides only guidance since process impacts and environmental burdens attributed remain specific to the sub-systems within a defined function boundary. It must be accepted that each LCA remains distinct and identifies the environmental impacts of a given system at a specific moment in time.

LCA as a philosophy

The aim of LCA remains to ascertain the true environmental impacts of a process for comparison between similar systems. LCA is therefore perceived as a holistic model for establishing a hierarchy of material sustainability via the evaluation of a function's life-cycle impact upon the environment.

To this end LCA increasingly influences government policy the on attainment of environmental sustainability, as recently highlighted in the publication of the European Commission's horizontal study into the enduse and disposal of PVC polymers.

The published reports [Argus 2000; BERTIN 2000; Prognos 2000; AEA 2000] and the resultant lifecycle assessments of material applications by the UK government [DETR 2001] have served to intensify the debate on the sustainable use of the material. Consensus arguably considers that the specification and use of the polymer is not sustainable and that methods for mitigating process impact are of primary importance. The EC and UK Government have subsequently earmarked the PVC sector for change.

The DETR study however contains several methodological inaccuracies that range from identification of FU and inconsistent systems boundaries to incorrect allocation procedures. Moreover although the cumulative impacts return statistical variations in the region of six per cent, the study concluded that timber remains environmentally preferred option. The authors of the report nevertheless accept that any data that display statistical variations in the region of up to 20 per cent should be discounted due to the variances present in generic data sets adopted.

The quality of LCA remains dependant on the data available, the boundaries set and the assumptions made. In turn, the formulation of data becomes a key element in achieving an effective LCA. What is, and is not included, provides the basis of successfully determining the function's environmental impact.

Thus functions must not be advantaged on the basis of individual results. Setting system boundaries to the winning and conversion of materials into a product - a “cradle to gate assessment” - will enable, for example, timber frame joinery to display significant ecological advantages over all other framing materials. Consideration of “cradle to grave” - service life, heat-loss, re-use and end-use opportunities however results in the timber systems being no longer the optimum environmental option [Krähling 1999; Richter 1995; IKP 1998].

The limitations of LCA return the nature and choice of assumptions made in the Goal and Scope [ISO 1997a]. Studies by SETAC [CML 1994] Lave et al [1995] and Janssen [1998] concur that identification and implementation of system boundaries remain the greatest weaknesses. Ayres [1995] enforces this view further with an analysis of several published LCA assessments recording significant errors in data generation due to the failure to enforce consistent procedures in data collection.

Conclusion

LCA provides a positive contribution to environmental issues by establishing a function's impact within a system boundary and, by identifying the critical life-cycle stages, forms the basis of environmental improvement. As a tool, LCA nevertheless remains a complex multi-dimensional model. All actions associated with the function, from mineral extraction to product assembly, use and re-use, recycling and final disposal require to be considered. Furthermore, as LCA is concerned with the performance of these actions, technical constraints compound the effectiveness of assessment. LCA does not however ascertain a single correct answer but rather provides an indicative assessment of the life-cycle impacts of a specific function, under specific circumstances, over a specific moment in time.

As a philosophy, LCA enables the increasingly important environmental issues to be provided with a framework for action and improvement. Well-reasoned studies therefore instigate environmental debate, allowing discussion to change from single issues to comprehensive, holistic understanding. The design of LCA is thus increasingly perceived as being an ideal methodology for identifying improvements, benchmarking functions and aiding long term strategic planning in the form of government policy [DETR 2000: PPG10].

Yet by identifying situations at a specific moment in time, LCA provides only a partial answer. Indeed, as no assessment will cover all dimensions of process operations and environmental management, LCA will never be universally definitive. Fundamentally LCA remains an anachronism. Hence it is necessary for interested parties to adopt a more pragmatic view - highlight trends, enhance the understanding of ecology and anthropogenic impact, identify issues for further investigation. LCA subsequently aids the decision making process, not replaces it.

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