Environmental Life-Cycle Assessment: A Tool for Public and Corporate Policy Development

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SUMMARY

Life-cycle assessment (LCA) is a methodology for analyzing the environmental interactions of a technological system with the environment. Early forms of LCA were used in the United States in the late 1960s for defining corporate environmental strategy, and later in the 1970s by government agencies as an aid for developing public policy. In the late 1990s, LCA emerged as a worldwide environmental management tool in the form of the ISO 14040 series. Despite relatively limited use in the Philippines, there is considerable potential for its utilization in both public and private sectors. For example, LCA can be used to assess different technologies in order to identify the best environmental option; alternatively, it can be used to provide a scientific basis for developing sound environmental strategies and policies in government or industry. Current LCA resources in the Philippines are limited, but in the past decade De La Salle University – Manila has gradually developed the capacity to engage in scientific research, technical consultancy and training in this field. A description of some current projects undertaken by the LCA research group is given.

Key Words: Life-cycle assessment (LCA), environmental management, decision support

1. Introduction

Development of truly effective environmental policies and strategies requires proper scientific basis. Life cycle assessment (LCA) is a framework and methodology for the identification of environmentally friendly products or processes. It is characterized by the analysis of cumulative environmental impacts over extended system boundaries. While conventional environmental assessment techniques focus only on either manufacturing processes or end-of-life disposal (or reuse), LCA considers the life cycle of a system, or the entire chain of events and activities that are necessary to support the product or process (SETAC, 1991; ISO, 1997). This is often called the cradle-to-grave approach, and has the obvious advantage of revealing potentially significant but “hidden” environmental impacts. Instead of focusing attention on large, concentrated, and readily apparent point sources of impacts – for example, a manufacturing plant – LCA also takes into account dispersed activities whose cumulative effects may prove to be critical as well. The life cycle concept thus gives a more accurate picture of the environmental impacts than conventional techniques; it evolved over the last three decades from a relatively vague framework for conducting assessments, into a rigorous set of internationally standardized guidelines.

2. History of LCA

The earliest forerunners of LCA were the Resource And Environmental Profile Analyses (REPAs) of the late 1960s and early 1970s. A series of studies were conducted by the Midwest Research Institute, and later by the consulting firm Franklin Associates Ltd., mostly for the private sector. The Coca Cola Company and Mobil Corporation were two of the firms for which REPA studies were done (Assies, 1993; Curran, 1996). A REPA study of different beverage packaging systems by Hunt et al (1974) was a typical example of these LCA predecessors. Interest continued through the 1980s, with studies by Gaines (1981) and Lundholm and Sundstrom (1985) being typical of the REPA studies used for policy- and decision-making. As the term REPA suggests, these early studies emphasized raw material demands, energy inputs, and waste generation flows; attempts on more sophisticated analysis through environmental impact classifications would come later in the evolution of LCA methodology.

Another early type of LCA emerged in the late 1970s in the form of net energy analysis (Boustead and Hancock, 1979). During the global oil crises of 1973 and 1979, many countries, including the Philippines, the United States and Brazil, began to explore petroleum substitutes. Bioethanol (ethyl alcohol produced through the fermentation of carbohydrate biomass) was one of the most extensively tested fuel; Brazil was particularly successful in its commercialization, and its *ProAlcool* program has continued for the past 20-odd years (Moreira and Goldemberg, 1999). One of the problems that became apparent was that the production of bioethanol on a life-cycle basis was highly energy-intensive. Net energy analysis was used to compare the cumulative energy inputs into the bioethanol life cycle (including agricultural inputs for feedstock production) with the energy value of the final product; such a comparison gave a true indication of the extent to which a substitute fuel displaced conventional energy sources. Early studies in the United States found a net energy deficit – more energy was needed to make the alcohol than could be recovered from its eventual combustion (Chambers et al, 1979; Lewis, 1980). Such studies continued to be used for the assessment of bioethanol and other alternative fuels, with the net energy approach being favored in North America (Shapouri et al, 1995) and an alternative energy ratio approach being more common in Europe (Culshaw and Butler, 1992). Eventually these energy analysis techniques led to the emergence of specialized LCAs for fuel and energy systems. These LCAs are now called Full Fuel Cycle Assessments (FFCAs).

Modern LCA methodology is rooted in the development of standards through the 1990s. The Society for Environmental Toxicology and Chemistry (1991) published “A Technical Framework for Life Cycle Assessments,” the first attempt at an international LCA standard. It explicitly outlined the components of contemporary LCA: goal definition, inventory assessment, impact assessment, and improvement analysis. By extending LCA beyond the mere quantification of material and energy flows (the predominant theme in REPA, net energy analysis, and other early forms of LCA), SETAC paved the way for the use of LCA as a comprehensive decision support tool. Similar developments took place some time later in Northern Europe, particularly in the Scandinavia. In 1995 detailed LCA protocols were specified in the “Nordic Guidelines on Life Cycle Assessments” (Nordic Council of Ministers, 1995).

In the late 1990's, the International Organisation for Standardisation (ISO) released the ISO 14040 series on LCA as an adjunct to the ISO 14000 Environmental Management Standards. The series includes standards for goal and scope definition and inventory assessment (ISO 14041, 1998), impact assessment (ISO 14042, 2000a), and interpretation (ISO 14043, 2000b), as well as a general introductory framework (ISO 14040, 1997). The ISO 14040 series actually bears a strong resemblance to the original SETAC framework; Azapagic's review (1999) gives a comparison between the two LCA standards. However, because of ISO's dominant position in the development of international standards, the ISO 14040 series may eventually supercede the SETAC guidelines among LCA practitioners.

3. The Product Life Cycle

The life cycle of a generic industrial product was defined by SETAC (1991) as being composed of the following stages:

- *Raw Material Acquisition* – all activities necessary to extract raw material and energy inputs from the environment, including the transportation prior to processing.
- *Processing and Manufacturing* – activities needed to convert the raw material and energy inputs into the desired product. In practice this stage is often composed of a series of substages with intermediate products being formed along the processing chain.
- *Distribution and Transportation* – shipment of the final product to the end user.
- *Use, Reuse, and Maintenance* – utilization of the finished product over its service life.
- *Recycle* – begins after the product has served its initial intended function and is subsequently recycled within the same product system (closed-loop recycle) or enters a new product system (open-loop recycle).
- *Waste Management* – begins after the product has served its intended function and is returned to the environment as waste.

The interactions of these stages with each other and with the external environment are shown in Figure 1. The combined stages constitute the entire cradle-to-grave system.

Truncation of the chain yields partial life cycles which in some cases may be sufficient for the analysis demanded by the study objectives (Todd, 1996). There are three variants of partial LCAs:

- *Cradle to Gate* – analysis upstream of point of truncation.
- *Gate to Grave* – analysis downstream of point of truncation.
- *Gate to Gate* – analysis between two points of truncation.

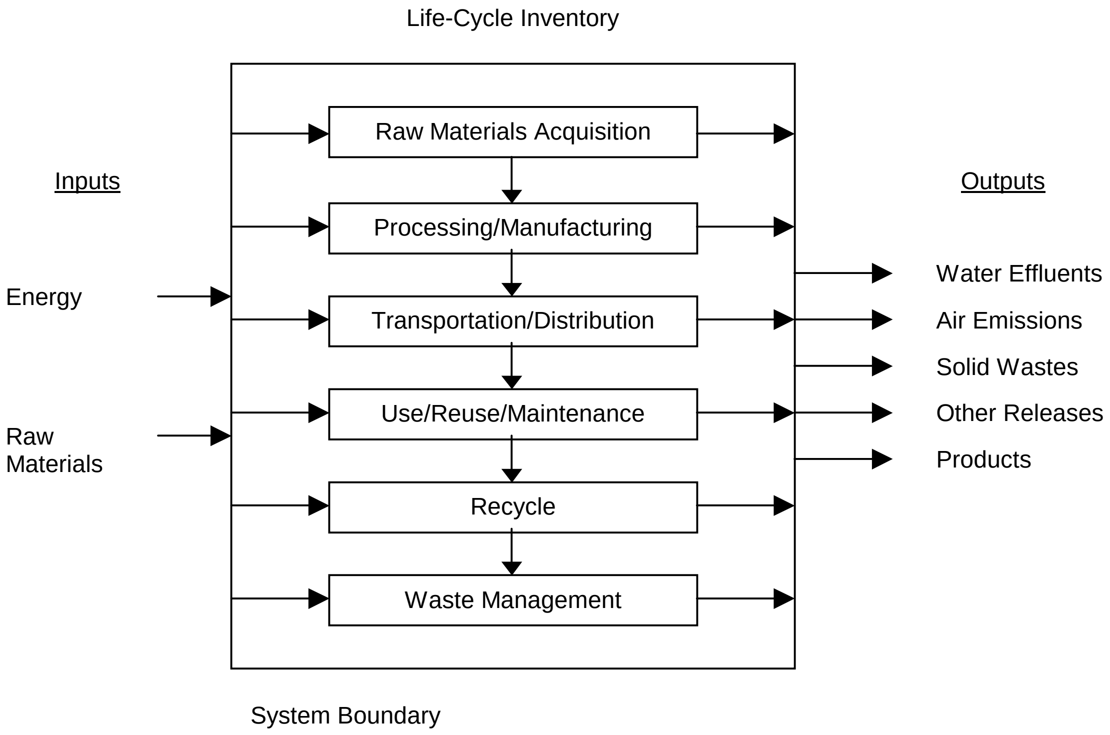

Figure 1 Stages in the Life Cycle of a Product (SETAC, 1991)

4. Key Features of LCA

LCA is a holistic framework that is distinguished by the following features:

- *Macrosystem or "cradle-to-grave" perspective* – LCA analyzes environmental interactions throughout the chain of activities supporting a given process or product technology.
- *Multicriterion perspective* – LCA analyzes different pathways by which environmental damage is done. This approach gives a balanced scrutiny of both immediate or local impacts (e.g., human toxicity, smog formation) as well as long-term or global concerns (e.g., global warming, depletion of non-renewable resources).
- *Functional unit perspective* – comparison and analysis of alternative technological systems is based on equivalency of service delivered. For example, instead of comparing the environmental impacts of 1 liter of gasoline with 1 liter of diesel, environmental assessment is normalized with respect to the final service delivered. A more appropriate basis is 1 km of travel by gasoline- and diesel-powered vehicles of equivalent size.

5. Components of LCA

Early LCA-type studies focused exclusively on quantifying material and energy flows. The emergence of modern LCA standards in the 1990s (SETAC, 1991; Nordic Council of Ministers, 1995; ISO, 1997; ISO, 1998) was characterized by an increase in the level of sophistication of the general life-cycle concept, which has now been extended to include four components for a full LCA. These components are:

- *Goal and Scope Definition* – specifies the objective of the assessment as well as the assumptions under which all subsequent analysis is done. LCA objectives can be classified broadly into system improvement studies, in which the goal is to identify opportunities for reducing the environmental effects of an existing system or process, and comparative studies, in which the intent is to select an optimal product of process from a number of predetermined alternatives. Scope definition involves specifying system boundaries, functional unit, allocation assumptions, inventory parameters, and impact categories that will be used. Depending on the scope and objectives, it may not be necessary for an LCA to have all four components. In some cases, for example, a simple inventory assessment may be sufficient.
- *Inventory Analysis* – involves the quantification of environmentally relevant material and energy flows of a system using various sources of data. Essentially, an accounting of system inputs and outputs is performed. The data used may come from a variety of sources, including direct measurements, theoretical material and energy balances, and statistics from databases and publications.
- *Impact Assessment* – analyzes and compares the environmental burdens associated with the material and energy flows determined in the previous phase. The conventional approach is to classify the inventory flows into specific impact categories (e.g., global warming, resource depletion, ecotoxicity). Normalization and weighting (or valuation) of the impacts is also included in this stage. If necessary, the individual impacts can then be aggregated into a single composite environmental index.
- *Interpretation* (ISO, 2000b) or *Improvement Assessment* (SETAC, 1991) – utilizes the results of the preceding stages to meet the specified objectives. Typically this phase will generate a decision or plan of action. For diagnostic LCAs, the data is used to identify critical segments or “hot spots” in the life cycle which contribute disproportionately to the total system environmental impact. These problem areas can then be eliminated or reduced through system modifications. In the case of comparative LCAs, the competing system life cycles are ranked based on environmental performance and the optimal alternative is selected.

Azapagic (1999) points out the strong similarities between the SETAC and ISO standards. Aside from terminology, the principal difference lies in the fourth component of LCA. In the SETAC framework, the principal focus of this final improvement assessment stage is to identify opportunities for improving environmental performance. Under the ISO framework, the fourth phase is called interpretation and is extended to include sensitivity analysis and final recommendations.

The interactions among the four LCA components are shown schematically in Figure 2.

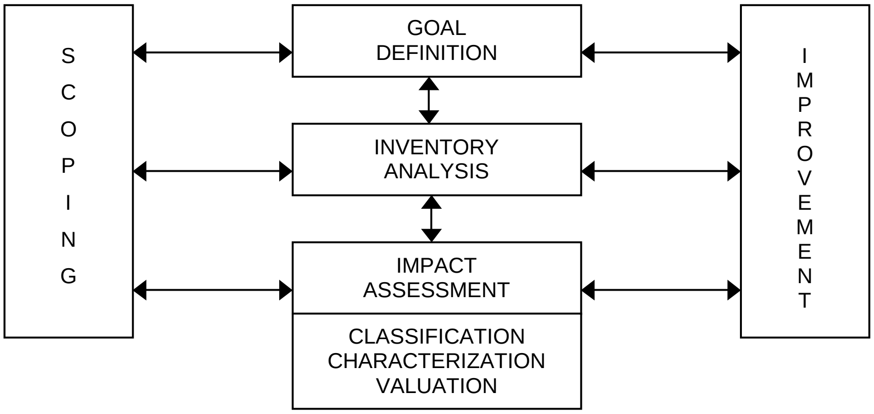

Figure 2 Interactions Among LCA Components (SETAC, 1991)

6. Uses of LCA

LCA is one of many environmental management tools (ISO, 1997). It can be used by governments, private firms, consumer organizations, and environmental groups as a decision support tool (Wenzel et al, 1997; Krozer and Vis, 1998; Field and Ehrenfeld, 1999). The scope of the decisions covered by LCA ranges from broad management and policy choices to specific selection of product or process characteristics during design. Also, LCA may be applied prospectively or retrospectively (Ludwig, 1997).

LCA applications (ISO, 1997) can be classified into the following:

- Indentification of opportunities to improve the environmental aspects of products at various points in their life cycles.
- Decision-making in industry, government, and non-government organizations (NGOs).
- Selection of indicators of environmental performance and measurement procedures.
- Marketing, including ecolabelling and improvement of corporate image.

Table 2 lists LCA applications based on broad objectives of “focus” and “choice” as suggested by Wenzel et al (1997). “Focus” refers to a stand-alone diagnostic LCA to identify points of interest within a single life cycle system, whereas “choice” refers to comparative LCAs of competing alternatives with the ultimate objective of ranking and selection. They also give a more detailed description of the uses of LCA in the private and public sectors as well as NGOs. LCA applications grouped according to users are given in Table 3.

Table 2 LCA Applications According to Objectives (Wenzel et al, 1997)

Objective	Application	Support for Decision
Diagnosis	Product Development	Background for environmental specifications; design strategies, principles and rules.
	Ecolabelling	Identifies important environmental proerties for the product category.
	Community Action Plans	Identifies environmentally important product groups.
Selection	Product Development	On-going identification of the best choices from alternative solutions.
	Cleaner Technology	Identifies the best available technology by means of LCA.
	Community Action Plans	Identifies the best community strategy for a certain problem or product.
	Consumer Information	Documents potential environmental impacts from a certain product

Table 3 LCA Applications According to User Type (Wenzel et al, 1997)

LCA User	Application	Example
Government	Community Action Plans	Incineration versus Recycling
		Public Transport Systems
	Environmentally Conscious Public Purchase	Cars, Office Supplies
	Consumer Information	Ecolabels & Standards
Company	Establish Environmental Focus	Identification of Areas of Improvement
		Product-Oriented Environmental Policy
		Environmental Management
	Design Choices	Concept Selection
		Component Selection
		Material Selection
		Process Selection
	Environmental Documentation	ISO 14000 Certification, Ecolabels

Although LCA is often utilized as an assessment tool for management-level policy formulation, recently there has been more emphasis on its use as a process or product design aid at the technical level (Azapagic, 1999). This approach involves the use of LCA for:

- *Process Technology Selection* – determination of the best pathway by which a specified product or service can be provided, through selection from a number of competing alternative processes. This application extends the practice of choosing the Best Practicable Environmental Option (BPEO) to incorporate life-cycle considerations.
- *Process Optimization* – extends conventional process optimization practice, including mathematical programming techniques, to include objective functions that reflect environmental life-cycle considerations. This application also includes improvement of existing processes through retrofits and modifications.
- *Process Design* – extension of DFE methodology to a life-cycle basis, under the emerging framework of life cycle process design (LCPD). Product and process design are integrated; this key feature allows more flexibility in achieving full environmental benefits.
- *Product Development* – selection of environmentally sound features and components of an industrial or commercial commodity. Potential applications include screening of environmentally sound packaging and raw materials.

7. Survey of LCA Applications

LCA has been used extensively in Europe and North America by government and business organizations. These assessments have been used both for streamlining day-to-day operations and for defining long-term research and development priorities. Typical success stories include:

- Use of LCA by the United States Department of Defense to determine purchasing policies for office supplies, particularly the identification of environment-friendly paper (Goidel and McKiel, 1996).
- Development of the GREET software model by a research division of the United States Department of Energy for assessing the environmental benefits of different technological options for road vehicles (Wang, 1996). An updated version of this program was recently used by the Global Alternative Propulsion Center (GAPC) of General Motors Corporation to determine R&D priorities for the development of the next generation of motor vehicles (Wang, 2001; General Motors Corporation et al., 2001).

Table 4 lists other firms and government agencies that have successfully utilized LCA-based methods, as documented in Allen (1996), van Berkel et al. (1997), Graedel (1998) and Verschoor and Reijndrs (1999).

Table 4 Recent Users of LCA and Related Methods

Type of Organization	Name of Organization
Government Agency	UK Department of Trade & Industry US Department of Energy US Department of Agriculture US Environmental Protection Agency US Department of Defense
Private Firm	AT&T Procter & Gamble General Motors Corp. Volvo Credit Suisse The Body Shop BP Amoco IBM Motorola Dow Chemical Nestle Coca-Cola TetraPak Scott Paper ExxonMobil Shell Hoechst Monsanto

8. LCA Research in De La Salle University – Manila

De La Salle University – Manila has established itself as the leading Philippine institution in the field of LCA, thanks in part to links with the University of Portsmouth of the UK dating back to the early 1990s. A variety of activities have been undertaken during this period, such as:

- Utilization of LCA to identify clean production (CP) options in paper production (Culaba and Purvis, 1999; Pineda-Henson and Culaba, 2000) and semiconductor manufacturing (Pineda-Henson and Culaba, 2002). These projects culminated in the development of decision-support software that are can be used as an aid or substitute for human experts and consultants.
- Use of LCA to identify environmentally optimal alternative fuels for road vehicles. Alternative technologies evaluated include natural gas derivatives (Tan and Culaba, 2001b), bioethanol or alcogas (Tan et al., 2000), cocodiesel (Tan et al., 2002), hydrogen and electric power (Tan and Culaba, 2001a; 2002). Findings of the study have been encoded in the POLCAGE 1.0 prototype software model.
- Delivery of preliminary LCA training modules for the Department of Science & Technology (DOST). Further training of DOST staff will be carried out in the near future. These seminars will also be made available to other government agencies, particularly the Department of Energy (DOE) and Bureau of Product Standards.

Current and anticipated LCA projects in De La Salle University – Manila include:

- Development of generic commercial LCA software for use in industry
- Development and validation of streamlined (simplified) LCA methods
- Assessment of waste-to-energy technologies
- Detailed LCAs of cocodiesel, alcogas and hydrogen fuels for vehicular use
- Analysis of solar energy options for “green” buildings
- Development of optimal solid waste management techniques
- Development of a national and Southeast Asian LCA network

9. Conclusion

LCA has emerged as a highly effective and standardized tool for environmental managers and policy-makers. Successful application of LCA in both public and private sectors throughout Europe and North America amply demonstrated its effectiveness in addressing environmental concerns. At the moment, LCA remains a novelty in the Philippines. However, due to the concerted efforts of the LCA research group at De La Salle University, it has started to gain some recognition. It is anticipated that applications of LCA in defining public and corporate environmental strategy in the Philippines will become more prevalent in the near future.

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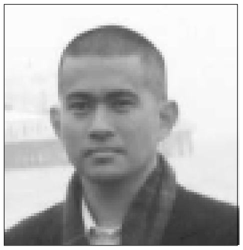

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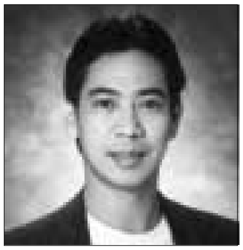

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