The Ecologically Sustainable Development Conference In Architecture And Building

1996 BPN-Solutions For A Sustainable Future

Life Cycle Analysis-How It Works And Practical Applications

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Summary:

DPWS leads NSW in Ecologically Sustainable Development (ESD) of the built environment in applying a range of environmental management strategies. In particular we are using the quantitative outcomes of Life Cycle Analysis (LCA) to establish benchmarks for *continuous improvement in procurement of goods and services and eco-design* of significant urban developments. At DPWS our current focus is on energy reduction, resource conservation and waste minimisation.

LCA is an accounting system used to determine the costs to the environment of human activities. It involves calculating and analysing the burdens associated with the production, use and re-use of utilities, goods and services over their life cycle. This includes processes such as cultivation, extraction, manufacture, delivery, utilisation, recycling and maintenance. In LCA, although we describe products, we really study the *processes that go to their manufacture, use and disposal*. It is usual to find that LCA results for a product will be different for each application. LCA results will vary with application, transport, climate and design so the intelligent practitioner looks at the application of a product to find the eco-burdens over its' life cycle.

Examples are shown from LCA's of design and construct school projects involving inventory of significant burdens associated with school homebases. Results from an inventory are used to show if qualitative *eco-design principals* have achieved intended improvements towards goals in areas such as ecosystem protection and energy conservation. In using this big picture analysis tool we find that rather than good or bad products there are only *better or worse technologies* in terms of their impact on the environment.

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1. INTRODUCTION

The increased regard for the environment is linked with the use of goods and services in society. Methods are available to *determine, understand and reduce* the environmental impact of human activity. Both *upstream issues* such as resource depletion and *downstream issues* such as waste management can be measured and assessment of their significance can be made.

For these reasons a system of environmental *accounting* called life cycle analysis (LCA) has been developed. This is the process of calculating and assessing the environmental *burdens* associated with the production, use, re-use and disposal of a product over it's life cycle or design life.

2. OBJECTIVES

To analyse the environmental burdens associated with an activity such as design, procurement and construction. This is then integral to *Environmental Management* as it provides an *inventory*, then shows where the *most significant impacts* are and where *improvement* can be most effective. [1]

3. MANAGEMENT APPLICATIONS

LCA is useful in process analysis, material selection, product evaluation, product comparison and policy making particularly in the areas of:

- waste management,
- energy reduction,
- depletion of natural resources.

LCA is used in benchmarking performance as a consecutively performed series of LCA's can refine design, construction, utilisation and performance *improvement* trends. [1,2]

4. BASIC PRINCIPLES

Any group of industrial operations can be regarded as a system of inputs and outputs. LCA determines different inputs and outputs using data which is analysed to reach conclusions about the significance of ecological burdens in order to provide management with results to underpin *decision making* and demonstrate performance related to organisational *policies, goals and investments.*

4. STAGES OF LCA

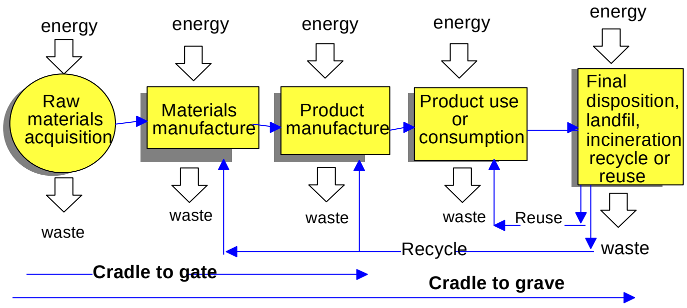
- Life Cycle Inventory (LCI) is a system of inventory accounts used to identify performance in areas such as resource and energy use as well as emissions to air, land and water.
- In Life Cycle Impact Assessment inventory results are compared with goals or compliance requirements to address ecological, health and safety and resource depletion criteria.
- Life Cycle Improvement Assessment applies inventory and impact assessment results to selected criteria to determine which part of the system needs most improvement as outlined in the emerging ISO 14000 series standards. [3,4,5]

5. SCOPE OF LCA

LCA is conducted in a system boundary such as “from cradle to gate” or “from cradle to grave”. *Cradle to grave* analysis includes all major raw materials and energy inputs as well as emissions during manufacturing and use up to and including burdens occurring at the end of the product’s life. *Cradle to gate* LCA is conducted in a system boundary that stops prior to product use.

Figure 1, a schematic view of a typical industrial system depicts the scope of LCA work including fuel and energy inputs, along with waste product, recycling and reuse outputs.

Figure 1. Typical LCA Scope of Work

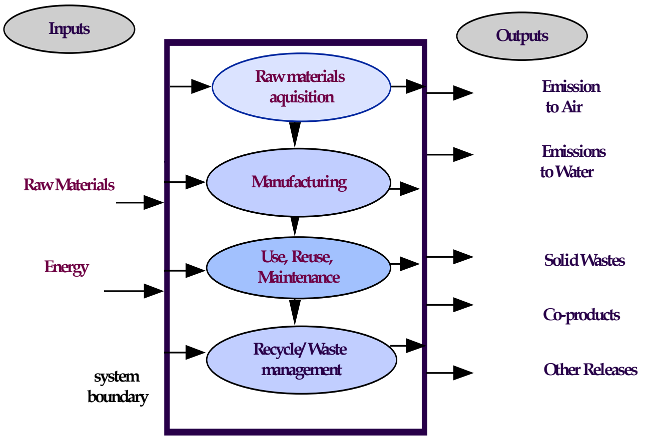


7. LCA SYSTEM BOUNDARY

Over a given design life, the LCA process accounts for the known environmental burdens, associated with raw material and energy inputs and outputs to air, land and water, co-products and recycling in acquisition, manufacture, use, reuse, maintenance and recycling. This is shown in Figures 2 and 3, schematics of LCA system boundaries including the following operations:

- raw materials growth, harvest and processing,
- mining and extraction of raw materials,
- manufacture and use of chemicals,
- fuel production for electricity and processing,
- transportation of intermediate materials.

Figure 2. Schematic Of The LCA Process And System Boundary



8. LCA INVENTORY Method

After flow charting all significant input operations for an industrial system, defined operations are entered into a computer database. [6] Calculations are made after these operations are linked to related downstream and upstream operations as shown in Figures 1 and 3. Fuel and energy data are entered for Australia or a specified country of operation on an international database. [2] Where a process generates several co-products the associated burdens are partitioned between them. Mathematical functions for each operation are based on a per functional unit output such as per unit area (m^2) or in a 2 room homebase.

8.1. Production Processes

As previously stated, each production process is drawn in a flowchart within a system boundary as shown in Figures 1, 2 and 3. Flow charts are used so sequencing of operations can be defined and allotted input numbers in the computer database.

8.2 LCA Example: Inventory from a School

Some examples taken from a Life Cycle Inventory (LCI) of the substructure of a 2 room school homebase are given in this section 8.3 to 8.8. No specific details are given as these examples are for illustration purposes only. Results were calculated for each process to determine associated environmental burdens which are discussed in sections as follows:

- Raw Materials
- Fuels And Feedstocks
- Emissions To Air
- Emissions To Water
- Solid Wastes Generated

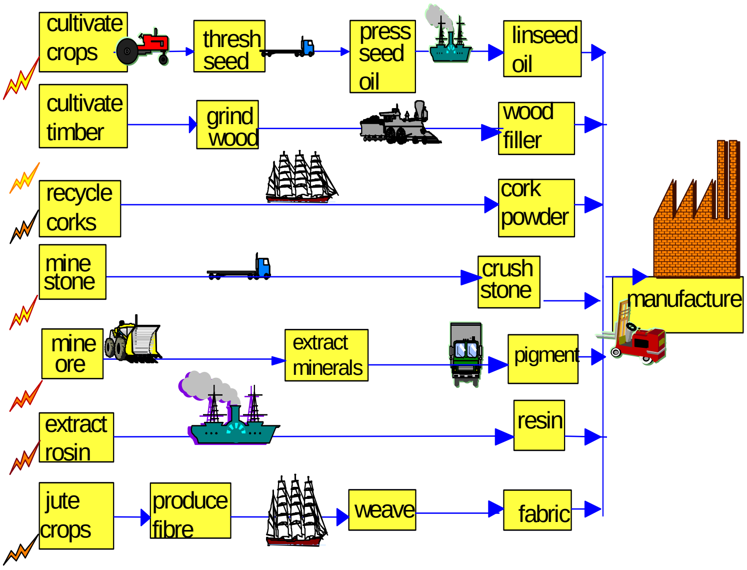
8.3 RAW MATERIALS

Table 1 shows the tonnages and types of major raw materials used in the substructure and all are classed as *non renewable resources*. [7, 8]

Table 1 Raw Materials Use (t)

water	203286	oxygen	62
gravel	28047	dolomite	44
sand	17352	olivine	33
limestone	7556	bauxite	15
Iron ore	5348	air	3
shale	379	bentonite	3

Figure 3. Typical Process Flow Chart



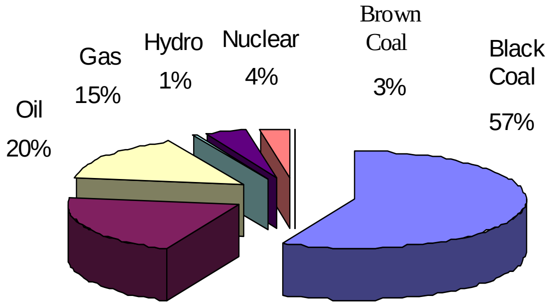
8.4 Fuels and Feedstocks

The total energy use was calculated for all processes from raw materials extraction to manufacture into products that were delivered to the school gate. So this was a *cradle to gate* LCI. To make the substructure about 123,000 MJ of energy was used, 92% of which came from oil, coal and gas. A source breakdown of energy is shown in Figure 4, a pie chart of the types and proportions of the total energy used:

- in the processing of the raw materials,
- for mode of electricity generation,
- and the fuels for transportation.

The nuclear energy component was for imported oil, processed in refineries powered by electricity from nuclear power stations.

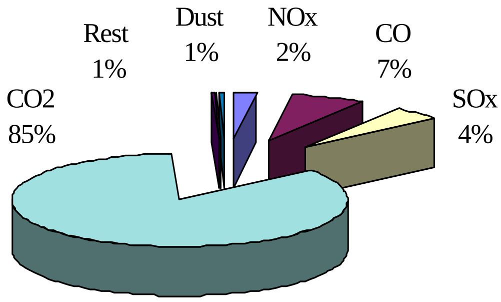
Figure 4 Gross Energy Uses



8.5 Emissions to Air

In this school substructure, the most significant emission to air was 10 tonnes of carbon dioxide, which is a greenhouse gas that came mostly from fuel production and use. Figure 5 is a pie chart showing major gases and dust in the pollutant stream.

Figure 5 Major Emissions to Air



Toxic air emissions included carbon monoxide, hydrogen sulphide along with hydrochloric and hydrofluoric acid fumes.

8.6 Emissions To Water

The 3.6 tonnes of suspended solids released to water came mainly from the various mining and quarrying operations used to acquire raw materials. Emissions to water included cyanides, chlorides, ammonium ions, lead, nitrogen compounds and phenols in the amounts shown in Table 2 below.

Table 2 Emissions To Water (mg)

suspended solids	3628872567	phenol	23434
COD	374961	F^{-}	12981
NH^{4+}	149017	Cl^{-}	12515
acid	64634	lead	2234
detergent/	47659	SO^{4--}	1245
other Nitrogen	44178	Na^{+}	779
Fe^{3+}	31383	dissolved solids	484
metals	28707	CN^{-}	336
HC	27378	dissolved organics	304

8.7 Solid Wastes Generated

The solid wastes generated are shown in Table 3 and these were made up of 97% mineral wastes most of which was returned to landfill at the mine sites. Slags and ash contributing 3% of the total solid waste are a result of energy generation. These are also returned to landfill though they may also be usefully incorporated into concrete products. No hazardous materials or regulated wastes were found.

Table 3 Solid Wastes Generated (kg)

mineral waste	34125
slags & ash	1117
mixed industrials	42

8.8 Conclusions from LCI Substructure

All major resources used, along with the source of significant environmental burdens produced in the construction of the substructure were determined. The most significant findings were that:

- most raw materials consumed were *non renewable resources,*
- the most significant emission to air was the *carbon dioxide from fuels* use and processing,
- toxic emissions to air included carbon monoxide, hydrogen sulphide, hydrochloric and hydrofluoric acid fume,
- *suspended solids* were the largest emission to water and these were mainly *from mining*,
- *toxic emissions to water* included cyanides, chlorides, ammonium ions, lead and phenols,
- the majority of solid waste were mineral wastes from the mining of raw materials.

9.0 THE SCHOOL INVENTORY

Further inventories were collated for all systems in the School homebase including:

- Flooring, Roofing, Insulation and Ceilings.
- Internal and External Walls, Trims and Finishes.
- Windows, Partitions, Doors, Fixtures and Fittings.

A Green Report Card for a project is compiled to shown the source of all significant burdens along with the overall resource, energy and raw materials use for each of the above listed subsystems. The reports are then compared with those from similar projects to analyse and exploit these quantitative results from the design and construct process against benchmarks of existing eco-designs.

11.0 IMPACT ASSESSMENT

DPWS has been set two tasks associated with environmental performance, namely:

- to be a leader in environmental design,
- to show commitment to the guiding principles of ecologically sustainable development.

LCA results are used as a management tool to demonstrate commitment to these tasks. Specifically this is achieved when the inventory results are assessed against goals and targets for managing environmentally improved outcomes in areas such as human health and ecosystem protection, remediation and conservation. Results are compared against progress towards goals achieved in established eco-design benchmarks of award winning projects. Some target areas where impacts are to be minimised or efficiencies maximised are listed below:

RESOURCE CONSERVATION:

- Increased Energy Efficiency
- Increased Water Conservation
- Waste Minimisation
- Increased Recycling Content

AVOIDANCE OF HARMFUL OUTCOMES:

- Avoidance of Sensitive Materials
- Avoidance of Chemical Pesticide Use
- Improved Pollution Reduction
- Maximised Indoor Air Quality

ENHANCEMENT OF THE ENVIRONMENT:

- Best Practice Biodiversity Protection
- ESD Timber Management and Use.

12.0 IMPROVEMENT ASSESSMENT:

The inventory calculation and impact assessment cycle is repeated for continuing improvement towards ESD. The ongoing assessment is to monitor progress and establish set points in environmentally friendly design. Established benchmarks of affordable ESD design are quantified using LCA and then the focus is on where further improvements can be made. The current DPWS targets towards ESD include:

- 10% reduction in current energy consumption,
- thermal insulation in all public buildings,
- water saving devices in all relevant projects,
- 30% reduction of construction waste,
- recycling on construction projects,
- policies for use of friendlier materials,
- restricted use of rainforest timbers.

13.0 CONCLUSIONS

- In this paper we have demonstrated how LCA is used to determine the costs to the environment of a project such as a school building. LCA has been shown to be a broad brush analysis that can account for environmental burdens from cradle to grave.
- Although we talk about products, in LCA we mean instead those processes that go to make, use and dispose of products. For a range of developments, burdens associated with any given product will vary with transport, climate, design and maintenance.
- LCA outcomes stress that rather than *good or bad materials there are really only better or worse technologies* for a given element in terms of their environmental impact.
- Because LCA results are expressed in quantitative terms they are widely applicable to management of procurement of goods and services, design and construction projects and investment planning.
- We have discussed a DPWS approach to quantitative LCA which we use to determine if *eco-design principals* have achieved improvements towards a range of ESD goals.
- DPWS leads NSW in Ecologically Sustainable Development (ESD) of the built environment in applying the quantitative outcomes of Life Cycle Analysis (LCA) to establish benchmarks for *continuous improvement* eco-design of significant urban developments.

14.0 List of References

1. SustainAbility, SPOLD & Business in the Environment. LCA Sourcebook; 1993
2. BCL, The Boustead Model for Life Cycle Inventory Calculations, Vol 1, Dec 1995
3. ISO 14041 (in preparation): Life Cycle Analysis- Life Cycle Inventory Analysis
4. Standards Australia/New Zealand. L C A: General Principles and Practices*:* DR94442,Dec 1994.
5. Hemenway,C.G & Gildersleeve,J. What is ISO 14000*?* CEEM Information Services: Virginia, 1995.
6. Austin, G.T. Shreve's Chemical Process Industries, 5th Ed; McGraw Hill, 1984.
7. AIA.,Environmental Resource Guide, John Wiley and Sons, Inc, USA. 1996.
8. Atlas of Australian Resources , Vol 5, 3rd Series, Aust.Gov. Printing Services. Canberra., 1988

15.0 GLOSSARY OF TERMS

Burden: The quantitative value assigned to any input or output for a given industrial system.

By-product: A useful product that is not the primary product of a process or system. In LCA, by-products are treated as co-products.

Co-product: A marketable by-product from a process or system. This includes materials that traditionally may be defined as wastes, such as industrial scrap, but that are subsequently used as raw materials in a different manufacturing process. Product and co-product share the environmental burdens of the system or subsystem from which they derive.

Environmental burden: The total releases of pollutants of different classes to the environment.

Feedstock value (energy of resource): The fuel value of raw material used in a product.

Functional unit: Specified function identified as a unit of comparison, eg paint for 1 square metre of wall over a period of 10 years.

Air emissions: A description of quantities and types of air emissions during a life cycle.

Water emissions: A description of the quantities and types of water emissions during the defined life cycle of a product.

Solid wastes: A description of the quantities and types of solid wastes produced during the defined life cycle of the product.

Gross energy requirements: A description of how energy is utilised during the defined life cycle of a product, whether as a fuel, or as electricity, or as a feedstock.

Gross fuel & feedstock requirements: A tabulation of gross fuel and feedstock requirements for each operation.

Gross raw materials requirements: A tabulation of the total quantity of raw materials associated with each operation during the defined life cycle.

Inputs: Specific environmental burdens which enter the system from the environment including resources and energy.

Inputs to unit operations: A cumulative tabulation of the results of calculations performed for each of the operations.

Intermediate materials: Materials made from raw materials to make final products.

Operation: A defined step, or steps, within an industrial process which may appear on a schematic diagram or flow chart;

Outputs: Specific environmental burdens which cross from the system to the environment. These outputs include environmental releases - emissions into air, emissions into water, and solid wastes - as well as products and co-products.

Process: An operation performed on one or more raw materials or intermediates leading towards the production of a product.

Raw material: A primary or secondary (eg recovered and/or recycled) feedstock used in a subsequent manufacturing process.

Recycling: Set of processes for reclaiming material, that would otherwise be disposed of, as a material input to a product or service system.

Renewable resource: Natural resource that is capable of regeneration.

System: A group of operations which, when acting together, perform a defined function. In a life cycle inventory, the scope of the system is defined by the boundary conditions.

Waste: An output with no marketable value that is disposed of to the environment. Any material released to the environment through air, water, and land, and has no beneficial use that crosses from the system into the environment and is returned to the ground (eg landfill or incineration).