

Life Cycle Assessment / Analysis of Concrete

Sustainability has become an important consideration for the construction industry, with an increasing number of clients taking account of environmental factors in relation to proposed design, materials and construction methods. Various tools for measuring sustainability have been developed including Whole life costing (WLC) and Life cycle assessment (LCA) also called Life cycle analysis.

Within the construction industry, LCA is mainly concerned with the environmental impact of materials and covers the process from winning the raw materials, through processing, construction, planned life time maintenance to demolition and disposal / recycling.

LCA is a useful tool for showing the environmental effect of using concrete in relation to other construction materials and for optimising concrete through materials selection and mix design to minimise environmental impact.

LCA of concrete must be carried out in the context of a particular structure or part of a structure called a **functional unit**; this could be the whole structure or just a floor slab, a foundation pile, a concrete bridge abutment or a precast beam. The LCA can be quantified for say, one cubic metre of concrete in that structure or for all the reinforced concrete in the structure. Alternatively it could be for one square metre of a precast block wall.

The functional unit will have a specification with respect to factors such as performance, working life, delivery, construction, maintenance and demolition. In comparing the LCA for alternative construction materials, it is essential that the functional unit for both options meets exactly the same overall specification or the LCA is not valid.

The LCA can be optimised for a functional unit by, for instance, altering the concrete materials and mix design to eliminate or reduce the need for protective coatings. The LCA is only valid for a particular functional unit as the specification and components may change for another relatively similar functional unit. For example, if the cement type and or content is changed, this may affect the LCA.

In producing the LCA of concrete for a particular functional unit, a **process tree** is drawn up. This details the **cradle to grave** life cycle of the concrete in the unit, detailing what specification items are included. An outline process tree is shown in fig 1. Note that in this process tree, the LCA does will include the environmental data associated with the day to day use of the structure such as heating, lighting and cooling costs of a building.

For each step in the process tree, all relevant environmental inputs and outputs (materials, energy, and emissions to air, water, soil or waste) are collected. This data collection is called a **Life Cycle Inventory (LCI)**.

Raw material suppliers should undertake an LCI for their products and provide the information for the first line of this process tree. This is often in the form of an **environmental declaration**, to the ISO 14020 series of standards. These declarations give the data collected from the LCI process in a standard form. An example of the main table in an environmental declaration is given in figure 2.

The LCI or environmental declaration information can then be combined with declarations from other material suppliers to give a new environmental declaration for a specific concrete mix. When combined with additional data for other steps in the process tree, it will give the LCA of the functional unit.

The LCA is often presented in the form of a contribution to **environmental impact categories** like energy use, depletion of natural resources, ozone layer depletion or "greenhouse" effect. Different LCA models may have different impact categories. See figure 3 for a typical set of impact categories. Other models try to rationalize the individual impact categories into a single environmental score.

The result of this analysis is called a **Life Cycle Impact Assessment (LCIA)** and contains an **environmental profile**. Figure 4 is an example of an environmental profile for a reinforced concrete element broken down into life cycle phases in the process tree. Individual impact values can vary by over 7 orders of magnitude so for presentation purposes they have been normalised to 100% for each impact category as shown in figure 4. However, note that some impacts will be over one millionth times smaller than others.

When combined with the actual values for each impact category, this information can be used to compare alternative construction options. For instance, changing the construction materials may improve some aspects of the profile e.g. initial energy use but if chemical waste and abiotic depletion is higher, the overall profile may be considered worse. Such decisions may depend on the clients view of the importance of each impact category with respect to the particular structure.

Material suppliers can use the results of both the LCI and LCA to target development or process optimisation into impact categories that have the largest effect on the environmental profile of functional units containing their product. Consultants can combine the materials LCA with additional information related to lifetime use to produce a Whole Life Costing (WLC)

There is no one internationally accepted method for demonstrating an environmental profile, however the basic requirements and processes for achieving one are laid down in the ISO-standards 14040 to 14043. The LCA methods all use the same LCI information but the form of the final analysis differs. Even within Europe there is no one agreed method but some of the more accepted methods are:

BRE Environmental profiles --- ⁽⁶⁾

- provides 13 environmental impact categories
- can be aggregated to a produce single score in UK Ecopoint products.

UK Ecopoints⁽⁷⁾

BRE single unit measurement of environmental impact. Calculated from a defined range of LCA data.

The Netherlands – CML-2 assessment⁽⁸⁾

Provides calculated values for the 13 environmental impact categories specified in Table 1. These may be subdivided into the individual steps of the process tree shown in Figure 4.

Eco-Indicator 99⁽⁹⁾

Contains a profile of 11 environmental impact categories. These can be averaged to give a single score.

Denmark – EDIP⁽¹⁰⁾

Gives a profile of 16 environmental impact categories.

There is on certification scheme in the UK designed to independently validate the results of an LCA for construction products. This is the BRE *Environmental profile certification scheme for construction products*⁽⁶⁾.

References:

INTERNATIONAL ORGANISATION FOR STANDARDISATION. ISO

(website: www.iso.ch/iso/en/ISOOnline.opennerpage)

- 1 **ISO 14020: 2000** *Environmental labels and declarations – General principles*, Geneva, Switzerland, 5pp.
- 2 **ISO 14040: 1997** *Environmental management – Life-cycle assessment: Principles and framework*, Geneva, Switzerland, 12pp.

- 3 [ISO 14041: 1998](#) *Environmental management – Life-cycle assessment: Goal and scope definition and inventory analysis*, Geneva, Switzerland, 22pp.
- 4 [ISO 14042: 2000](#) *Environmental management – Life-cycle assessment: Life-cycle impact assessment*, Geneva, Switzerland, 18pp.
- 5 [ISO 14043: 2000](#) *Environmental management – Life-cycle assessment: Life-cycle interpretation*, Geneva, Switzerland, 19pp.
- 6 BUILDING RESEARCH ESTABLISHMENT. *BRE environmental profiles of construction materials and components* (website: www.bre.co.uk/envprofiles).
- 7 DICKIE, I. and HOWARD, N. BRE Digest 446: *Assessing environmental impacts of construction – industry consensus, BREEAM and UK Ecopoints*, BRE, Garston, 2000
- 8 NETHERLANDS MINISTRY OF HOUSING, PLANNING AND ENVIRONMENT. *Life-cycle assessment* (English version available from vrom@dm.wegener.nl)
- 9 PRÉ CONSULTANTS BV. *Eco-Indicator 99* (website: www.pre.nl/eco-indicator99/default.htm)
- 10 TECHNICAL UNIVERSITY OF DENMARK. *Environmental design of industrial products (EDIP) programme*, (website: www.ipt.dtu.dk/~mic/EDIPbooks.htm)

Further reading

BRE Digest 452 – Whole life costing and life-cycle assessment for sustainable building design

German Building Materials Association – LCA of Building Materials (available in English)

Figure 1, Typical LCA Process Tree for Concrete Construction

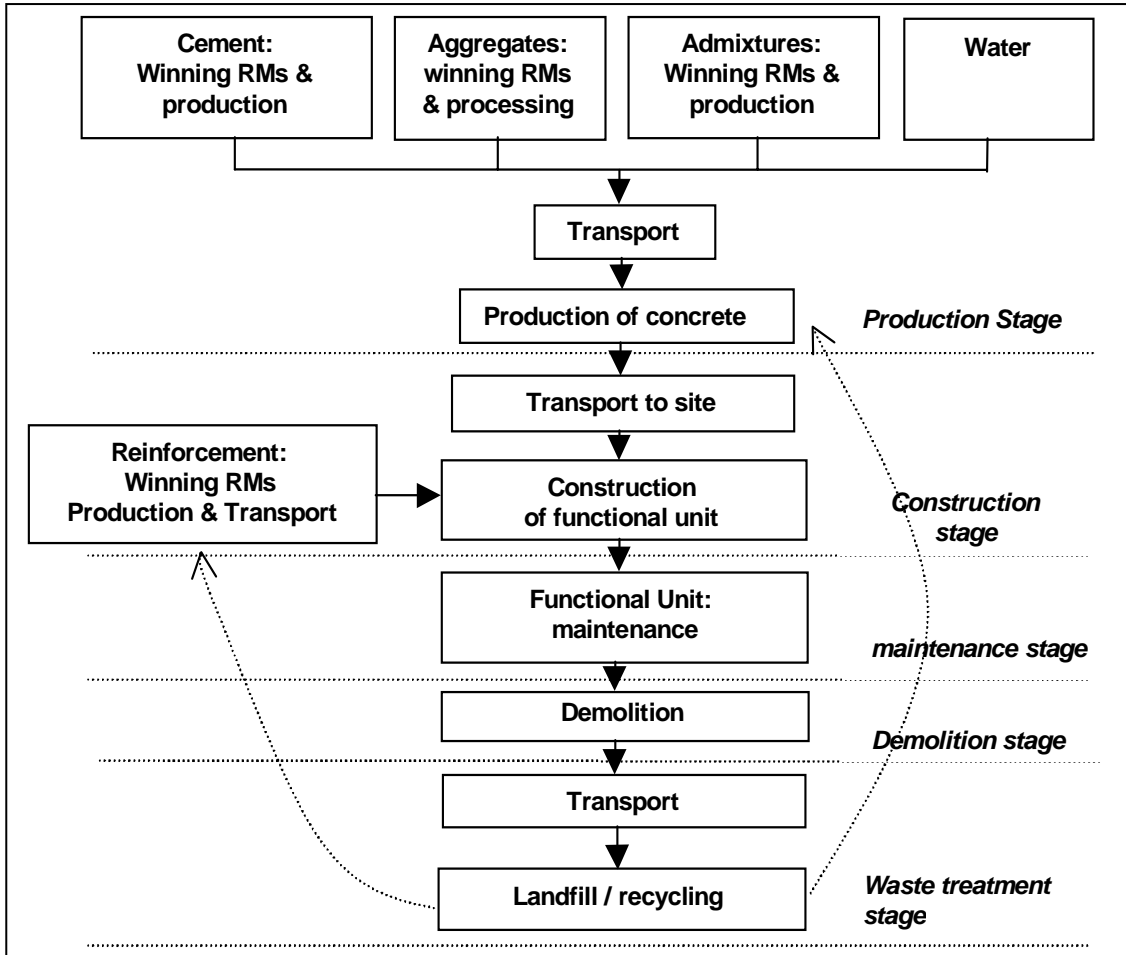


Figure 2, Typical Environmental Declaration For 1 kg of Product, (values removed)

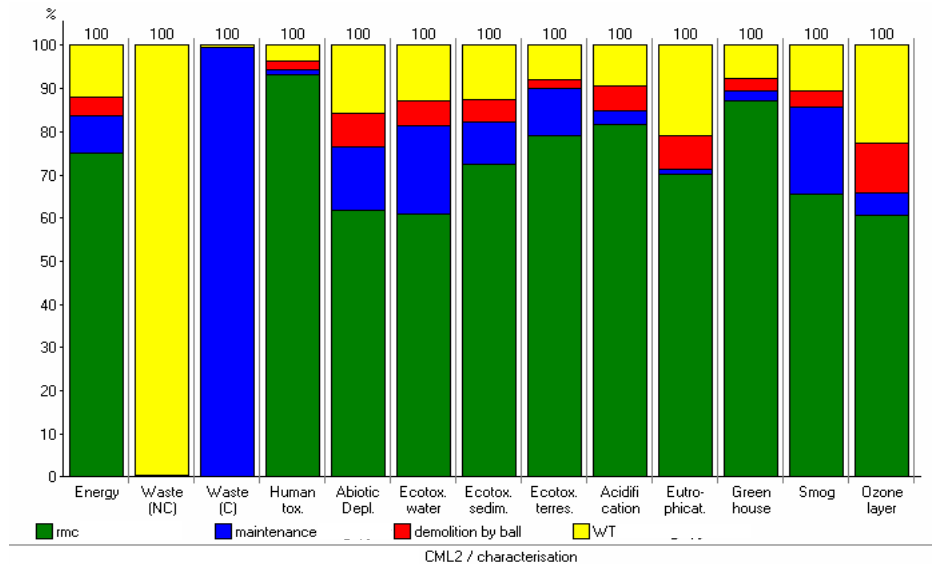
<i>Raw materials - input</i>	<i>Unit</i>	<i>Value</i>
coal	g	
crude oil (feedstock)	g	
crude oil (fuel)	g	
natural gas (feedstock)	dm3	
natural gas (fuel)	m3	
water	kg	
<i>Emissions to air</i>		
CO ₂	kg	
CO	g	
C _x H _y (VOC)	g	
methane	g	
methanol	g	
NO _x	g	
SO _x	g	
benzene	mg	
heavy metals	mg	
nickel (Ni)	mg	
mercury (Hg)	µg	
cadmium (Cd)	µg	
Halon-1301	µg	
<i>Emissions to water</i>		
barium (Ba)	mg	
copper (Cu)	mg	
formaldehyde	mg	
nickel (Ni)	mg	
PAH's	µg	
<i>Solid waste</i>		
Non-hazardous waste	g	
Hazardous waste	g	
<i>Total energy</i>		
Total energy	MJ	

Figure 3 Typical Impact Categories

Environmental effect	Description	Unit	Examples
Energy	Level to which energy is being used	expressed in MJ	
Waste (non-chemical)	Level to which waste, which is considered non-toxic, is released and which is not reused or recycled	expressed in kg	
Waste (chemical)	Level to which waste, which is considered hazardous, is released and which is not reused or recycled	expressed in kg	
Abiotic depletion	Level to which non-renewable resources are depleted	expressed as kg antimony-equivalents	coal, oil, natural gas, metal ores
Greenhouse effect	Level to which emissions contribute to global warming	expressed as kg CO ₂ -equivalents	CO ₂ , methane
Depletion of the ozone layer	Level to which emissions damage the ozone layer	expressed as kg CFC-11- equivalents	CFC's and halons
Acidification	Level to which emissions contribute to the acidification of soil or water	expressed as kg SO ₂ -equivalents	ammonia, SO _x , NO _x
Eutrophication	Level to which emissions eutrophy the environment with nutrients	expressed as kg phosphate-equivalents	nitric and phosphorous substances
Human toxicity	Level to which an emission is harmful to humans	expressed as kg 1,4-dichlorobenzene-equivalents	heavy metals, pesticides, PAH's
Ecotoxicity, fresh water	Level to which an emission to fresh water is harmful for animals and plants	expressed as kg 1,4-dichlorobenzene-equivalents	heavy metals, pesticides, PAH's
Ecotoxicity, sedimental	Level to which an emission to sediment in fresh water is harmful for animals and plants	expressed as kg 1,4-dichlorobenzene-equivalents	heavy metals, pesticides, PAH's
Ecotoxicity, soil	Level to which an emission to soil is harmful for animals and plants	expressed as kg 1,4-dichlorobenzene-equivalents	heavy metals, pesticides, PAH's
Smog	Level to which emissions contribute to photochemical smog creation	expressed as kg ethylene-equivalents	NO _x or volatile organic compounds

Figure 4, Example of the LCA environmental profile of a concrete element

All individual impact values normalised to 100% to show relative effects of process stages. Absolute values will also be available from the analysis.



Life Cycle Process stages (see fig 1)

Green: Production and construction, includes: shuttering, reinforcement, concrete, pumping, vibrating, curing

Blue: Maintenance (includes regular painting)

Red: Mechanical process of demolition

Yellow: Waste treatment of materials after demolition