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WHITE PAPER - LIFE CYCLE ASSESSMENT AND THE BUILDING AND CONSTRUCTION INDUSTRY

A REPORT PREPARED FOR BEACON PATHWAY LIMITED

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Creating homes and neighbourhoods
that work well into the future
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WHITE PAPER - LIFE CYCLE ASSESSMENT AND THE BUILDING AND CONSTRUCTION INDUSTRY

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1. INTRODUCTION

A key factor in achieving more sustainable housing is the environmental aspect, next to social, cultural and economic aspects. Environmental issues include energy use, by people living in a house, but also in producing building materials; the emissions related to energy use; resource consumption; and waste generation. Some key figures illustrate these issues:

- Nearly a third of all electricity is used domestically – in heating, lighting, and running appliances (Ministry of Economic Development, 2006)
- Domestic energy consumption is about 13 % of the total energy consumption in New Zealand (Ministry of Economic Development, 2006)
- Waste from construction and demolition may represent up to 50% of all waste for disposal (Ministry for the Environment, 2006)

There is a huge variety of environmental issues which occur at different stages of the life cycle of a building. Improving the sustainability of buildings, or more specifically the environmental performance of buildings, therefore requires input by all stakeholders involved throughout the life cycle. A number of steps need to be taken; firstly the key issues need to be identified, alternatives have to be assessed, and existing technologies and products need to be improved. Last but not least, the results of these analyses need to be effectively communicated to all stakeholders – policy makers, industry, and consumers.

Currently, there is no single formula or recipe available to do all this in one step and provide one simple solution. However, environmental life cycle assessment (LCA) provides a suitable tool for assessing the environmental performance of a building by taking a systems perspective over the whole life cycle of a product or service.

The concept of LCA, possible applications of the results and available tools and databases on a national and international level will be described in this paper.

2. WHAT IS LCA

Life Cycle Assessment is based on the concept of Life Cycle Thinking which integrates consumption and production strategies over a whole life cycle, so preventing a piece-meal approach to systems analysis. Life cycle approaches avoid problem-shifting from one life cycle stage to another, from one geographic area to another, and from one environmental medium to another.

Life Cycle Assessment is an analytical tool for the systematic evaluation of the environmental impacts of a product or service system through all stages of its life. It extends from extraction and processing of raw materials through to manufacture, delivery, and use, and finally on to waste management. This is often referred to as “cradle to grave”. A number of other environmental assessment tools are restricted to the production process, which is sometimes called “gate to gate” or in the case of embodied energy cover the life cycle from “cradle to gate” without taking the end of life into account.

2.1 Definition of LCA

ISO 14040 defines LCA as:

“… a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a product system;

- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences."

2.2 Systems perspective in LCA

The key concept in LCA is the systems approach. This means on the one hand to look at the whole life cycle of a building material from cradle to grave and on the other hand to focus on the function rather than the material. The definition of a functional unit is therefore a crucial element in any LCA.

The "functional unit" is the basis for the environmental assessment and it describes the system for which an LCA study is carried out. Rather than looking at a certain mass of material it looks at the function or the service which is provided by a certain product. In a building context that means that the emphasis shifts from the product level to building component level. For example the comparison between 1 tonne of construction steel, 1 tonne of timber, and 1 tonne of concrete would not comply with this approach. The functional unit, i.e. the basis for a comparison would be "one square metre of an external wall for a one storey residential building for a 50 year period". The respective masses of steel, timber, and concrete would be calculated on this basis. But the comparison wouldn't be complete if only these components were compared, because different additional materials are required for a timber or steel framed wall; internal and external claddings, insulation material, building paper, etc. For a concrete wall these additional materials would not be necessary, but reinforcing steel would be. For a fair comparison these materials have to be included as well. Furthermore, the weight of these constructions varies and therefore different foundations are required for different systems.

An LCA study of an insulation material could be based on the quantity required to provide an R-value of 2.5 $m^{2o}C/W$ in a timber framed wall for a period of 50 years, rather than a certain mass of the insulation material (due to the different performance of various insulation materials).

The functional unit for other building materials might be simpler. Window frames with the same size and thermal properties, for example, can be compared without taking the wall into account because it is assumed that the window frame choice will not affect the structural requirements (Kotaji 2003).

Looking at the whole life cycle of a building material is another key characteristic of LCA. For construction timber, for example, it is crucial to take not only the forestry stage into account but also end of life scenarios, where timber is either landfilled or burnt and provides energy. This would be similar in the case of aluminium where recycling is a common end-of-life scenario.

2.3 Elements of an LCA

An internationally accepted framework for LCA methodology is defined in AS/NZS ISO 14040 – 14043. These standards define the generic steps which have to be taken when conducting an LCA. The following section will explain these steps and give examples on how they can be applied to the building industry.

Four different phases of LCA can be distinguished:

Goal and Scope Definition: The goal and scope of the LCA study are clearly defined in relation to the intended application (ISO 14040).

Inventory Analysis: The inventory analysis involves the actual collection of data and the calculation procedures. The relevant inputs and outputs of the analysed product system are quantified and produced as a table. (ISO 14041)

Impact Assessment: The impact assessment translates the results of the inventory analysis into environmental impacts (e.g. climate change, ozone depletion). The aim of this phase is to evaluate the significance of potential environmental impacts. (ISO 14042)

Interpretation: In this phase conclusions and recommendations for decision-makers are drawn from the inventory analysis and the impact assessment. (ISO 14043)

These can be represented as shown in Figure 1. In practice, LCA involves a series of iterations as its scope is redefined on the basis of insights gained throughout the study.

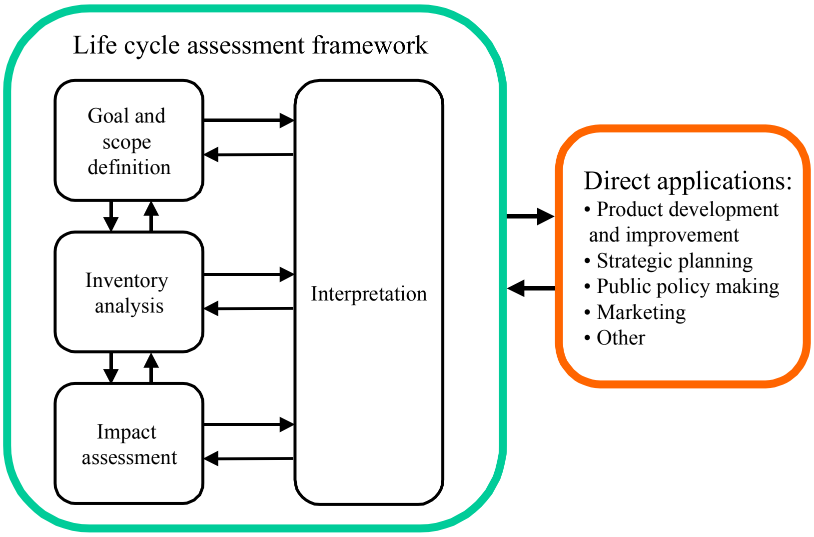

Figure 1 LCA framework (ISO 14040)

2.3.1 Goal and scope

This first LCA phase involves defining the goal of the study, its system boundaries, data requirements, functional unit, and any need for critical review. A clear definition of the goal of the study is important to avoid any subsequent misunderstandings about the wider applicability of the results. For example, a study carried out by a company to compare two alternative production processes may be adequate for internal decision-making, but its results may not be appropriate for public policy-making if the data are not representative of the national situation.

At a basic level, the goals for an LCA can be grouped into two categories:

- Hotspot analysis or product improvement from an environmental point of view: a system is studied in order to determine the stages in the life cycle with the greatest environmental impacts
- Comparative analysis: two or more systems are studied in order to compare their relative environmental impacts.

2.3.2 Data requirements and inventory analysis

The inventory analysis amounts to carrying out detailed material and energy balances over the system identified in Goal and Scope Definition. All quantities of material and energy inputs, and product and emission outputs to air, water, and land are compiled into one inventory. The overall product system should extend upstream to primary resources, and downstream to the point where material is disposed of. Treatment of solid waste should therefore be considered as part of the product system.

The methodology involves drawing a boundary around the system (system boundary) under analysis and quantifying the inputs and outputs across this boundary. Within the system, a number of discrete unit processes are identified, and input-output analysis is undertaken for each unit process (including transportation).

The quality of the LCA depends on the quality of the data sources. Actual fact based data which is measured on site provides high quality results. For generic data such as the provision of electricity New Zealand data should be used. However, sometimes measured data or New Zealand specific data might not be available. In these cases data from international databases can be used. However, this should not be used for the key material flows in an LCA and must be clearly documented. The system boundaries and the methodologies used to generate these databases have to be carefully checked and documented also.

2.3.3 Impact assessment

The environmental interventions calculated in the analysis are "translated" into environmental impacts during the impact assessment phase of LCA. The objective of this phase is to present the environmental impacts of the system in a form that meets the purpose of the study and can be understood by users of the results. Calculating the environmental impacts and compiling an environmental profile is the first step, optional elements are normalisation and weighting.

It is important to realise that the impacts are calculated at this stage on the basis of their incremental effect on the environment. This means that the actual effect is taken into account and not related to politically determined target values or emission thresholds. The aim is, therefore, general prevention of impacts, under the assumption that 'less is better'.

The systems approach is applied to this part of an LCA as well, by taking a number of different environmental impacts into account. The results are not restricted to the impact on climate change and energy use. The key environmental issues which are considered in an LCA include the following:

Global warming: Increasing amounts of greenhouse gases, such as carbon dioxide or methane, enhance the natural greenhouse effect and lead to an increase in global temperature. During the 20th century, the average global temperature has increased by about 0.6°C due to the enhanced greenhouse effect.

Ozone depletion: The ozone layer absorbs 95-99 % of the sun's harmful ultraviolet radiation and is therefore crucial for any life on earth. The natural Antarctic 'ozone hole' has been enlarging since the early 1980s.

Acidification refers to acid deposition from the atmosphere, mainly in the form of rain. Emissions of SO_2 and NOx can result in strong and damaging acids. Although there is currently no evidence of acid rain in New Zealand (MfE 2001), SO_2 and NOx emissions are closely monitored and regarded as an important issue in New Zealand.

Eutrophication refers to an increase in biomass production due to addition of nutrients, mainly nitrogen (N) and phosphorus (P), to soil or water. It leads to reduction in species diversity, often accompanied by massive growth of dominant species "algae bloom". In New Zealand this problem is well known in the context of the lakes in the Bay of Plenty.

Photochemical oxidant formation – also called "ground level ozone formation" describes the formation of reactive chemical compounds from NOx emissions with VOC emissions by the action of sunlight. Ozone (O_3), a form of oxygen, is the most important chemical in this group. In contrast to the protecting role of the ozone layer in the stratosphere, ozone in the troposphere is toxic. Ozone formation, sometimes referred to as "summer smog" is mainly an issue on sunny days in larger cities with a lot of traffic.

2.3.4 Interpretation

The final phase of an LCA is the interpretation phase. During this phase, the results of the analysis are discussed and opportunities for reducing the environmental impacts associated with the functional unit are identified and evaluated. ISO 14043 states that this phase should include communication of the study results "in a form that is both comprehensible and useful to the decision-maker."

2.3.5 Third party review

Depending on the goal of the study, a third party review may also be required. If the results of an LCA are going to be published in some form, either for marketing or to feed into an environmental label, the study should be made according to the ISO standards 14040 – 14043. These standards set a framework for the generic steps which have to be taken when conducting an LCA. According to the standards it is also mandatory to get a third party review of the LCA. This can either be done by another LCA expert, independent of the LCA or by a panel of interested parties. The review statement and recommendations along with the responses shall be included in the LCA report. This ensures that not only that the methods used are consistent with the ISO standards and scientific model, but also that the used data and conclusions are appropriate and in line with the goal of the study.

3. TOOLS

Modelling the whole life cycle of a product, and all related material and energy inputs as well as the emissions and translating these into environmental impacts is quite a complex task. It requires experience with the LCA methodology, but also a good understanding of the life cycle of the product. A close dialogue between the LCA practitioner and the stakeholders, mainly the product manufacturer, is therefore crucial. A number of software tools are available to assist the LCA practitioner in processing the data. The two most common programmes used in New Zealand and Australia are:

- GaBi (Germany) http://www.gabi-software.de/
- SimaPro (Netherlands) http://www.pre.nl/simapro/default.htm

Both programmes comply with the ISO requirements for LCA and use the same methodology for translating an emission into an environmental impact. The results of an LCA done in GaBi are therefore compatible with one done in SimaPro, assuming that goal and scope of both LCA's are the same.

The differences are in the number of generic datasets which are available in each software package and in the modelling options. GaBi for example allows a monetary assessment in addition to the environmental assessment.

4. APPLICATIONS AND USERS OF LCA

Information about the environmental impacts associated with a product's life cycle can be used as a decision support tool as well as for raising awareness of environmental issues. Due to its scientific and quantitative nature LCA can be used to replace conventional wisdom and intuitive assessment of environmental impacts. Improved communication is therefore one of the main functions of LCA. The results of an LCA can assist across a wide range of applications which include:

- communication about the environmental aspects of products
- product and process improvement
- product and process design
- development of business strategies, including investment plans
- setting ecolabelling criteria
- developing product policies
- developing policy strategies
- purchasing decisions.

The wide range of possible applications implies that there is also a range of stakeholders who might use LCA results. These include:

- industry and other commercial enterprises,
- governmental and regulative bodies,
- consumer organisations and environmental groups,
- consumers.

4.1 User groups

Industry

Industry uses LCA for product improvement and product design, by identifying environmental hotspots in production processes, but also in upstream processes or downstream processes such as the use phase of a product. For example improving the durability of cladding product might require a higher environmental cost in the production stage, but looking at the whole lifetime of a house it might lead to significant savings by reducing the need for replacement.

LCA results can also be used as part of an environmental management system to prove continuous improvement or for providing information for ecolabelling.

Governmental and regulative bodies

Governments can use LCA in a policy making context, but also in their role as a consumer for sustainable procurement. Quantitative data from LCA can be used for the development of waste and transport strategies. Decisions about introducing subsidies for recycling or building technologies and materials can for example be based on LCA results.

Consumer organisations and environmental groups

Ecolabelling is one of the main uses of LCA data for consumer organisations. In many countries the LCA of several representative products in a product group is used to set ecolabelling criteria. Ecolabels based on LCA data reflect a more holistic view by looking at the whole life cycle of a product. Energy rating of household appliances is a good example for this. It’s not the manufacturing of the product which is important, but the use of energy in the use phase.

Consumers

Consumers are “end users” of LCA studies and can use the results for purchasing decisions. Trustworthy, transparent and comparable environmental information which is often lacking can be provided from LCA studies.

4.2 Examples for the use of LCA by governmental and regulative bodies in the building sector

A number of international government initiatives in the building and construction area are already based on LCA. Some examples are:

Code for Sustainable Building in the UK

The Code for Sustainable Building in the UK is a voluntary initiative, by Government and Industry, to actively promote the transformation of the building industry towards more sustainable practices by requiring buildings to use:

- Energy resources more efficiently;
- Water resources more efficiently;
- Material resources more efficiently; and
- Practices and materials designed to safeguard occupants' health and well being.

The code aims at introducing a rating system for the sustainability of buildings. Life cycle assessment data provided by manufacturers or suppliers are valuable for establishing the relevant information.

Guideline for Sustainable Buildings in Germany

The Guideline for sustainable building in Germany is a guideline which should be followed for all governmental buildings. For the environmental aspect it requires the use of sustainable materials. Data based on life cycle assessments (LCA) according to the ISO standard 14040 should be used to determine the environmental preferences of a product.

The Austrian home subsidy model

In Lower Austria, the home subsidy system is based on social aspects and on the level of sustainability achieved. 100 points can be reached through sustainable measures, one point corresponding to € 300 of a long-term, favourable loan. The prerequisite is a low heating energy demand (< 50 kWh/m^2a). Rewarded measures are, e.g., the application of renewable energy sources, controlled ventilation and a green roof. A maximum of 15 points can be obtained for the use of ecological materials. The materials are judged based on the life cycle assessment data for energy, acidification and global warming potential of the product. The use of certified products and wood is preferred, PVC should be avoided. The overall goal of the subsidy model is to promote homes with low energy consumption, low greenhouse gas emissions and low maintenance costs while providing a high standard of living.

US: LEED

LEED is a rating tool for buildings in the US which provides a complete framework for assessing building performance and meeting sustainability goals. It has been adopted nationwide by federal agencies, state and local governments, and interested private companies as the industry standard of measurement for green building. It is compulsory for some government agencies. A review of this rating tool is currently under way with the goal of including LCA.

5. WHAT HAS BEEN DONE IN NEW ZEALAND

LCA studies have been conducted in New Zealand since the late 1990s. One of the first overviews on LCA in New Zealand was prepared by Jaques (1998). The number of LCA studies being conducted in New Zealand is increasing steadily. Two workshops for LCA practitioners in New Zealand (2005 and 2006) show that capability within New Zealand is growing, and the number of case studies (most nonbuilding-related) is increasing (Nebel and Nielsen, 2005, Nebel, 2006). These include not only publicly funded studies, but also industry funded studies as well as individual companies who undertake LCAs for their own products.

Key projects which cover a number of building materials are briefly described below.

5.1 NZIA Environmental Material Comparison Charts

NZIA Environmental Material Comparison Charts (1996) were published by NZIA and are designed to allow designers, builders, and specifiers to make environmental assessments of common construction product groups, based on life cycle aspects. However, by far the most information is text based (i.e., descriptive), with the energy information being the exception. There are 20 charts to cover most common building elements - such as structure, roof and wall cladding types, interior flooring, ceiling and internal wall linings, interstitial element, etc. Product composition, life cycle stage (from materials acquisition through to demolition/disposal), and quantitative energy data of each building element are examined. In contrast to the EnviroChoice system, this tool is not product specific and is not based around a certification performance threshold.

The charts are very user-friendly, with each chart being laid out in a three A4 page fold-out fashion, and therefore easy-to-use. However, being written in 1996, the charts need to be updated to account for changes in the manufacturing processes in some elements/materials.

5.2 Life cycle environmental inventory of 12 low energy technologies for New Zealand houses (ZALEH)

This project is a subset of the BRANZ Ltd Zero and Low Energy Household (ZALEH) project. The objective was to provide a life-cycle based inventory of various materials and technologies in several low-energy house designs, examining the net resulting embodied and operational-related energy requirements and their associated CO_2 emissions only. Three time frames examined - at 50, 100 and 150 years.

The 12 materials/technologies were selected by an expert group. The 'low energy' technologies to be examined were:

1. wood fibre insulation
2. high efficacy lights
3. high efficiency refrigeration
4. aspirated solar air heaters
5. co-generation
6. straw bale
7. straw clay
8. adobe
9. phase change materials
10. solar hot water
11. photovoltaics
12. wind generation.

This study has yet to be completed.

5.3 Embodied Energy and CO_2 Coefficients

Alcorn (2003) has compiled New Zealand specific data on embodied energy and CO_2 emissions for approx. 60 different building materials. These range from aggregate (river or virgin rock), over cement, copper, to steel and timber. The study covers energy consumption and CO_2 emissions from resource extraction, transport and processing, i.e. “cradle to gate”. Included are ingredients, energy inputs, transport, capital equipment, outputs and extra information. Use phase, demolition and end-of-life are not taken into account.

6. WHAT HAS BEEN DONE INTERNATIONALLY

A number of specific LCA based software tools for the building sector have been developed overseas for the assessment of building materials, building products, or whole buildings. The most common and widespread building-related databases and tools are briefly described.

6.1 **Athena Environmental Impact Estimator** (Canada/U.S.)

The Athena Sustainable Materials Institute in Canada has developed user-friendly software for the **LCA of buildings**. The tool allows architects and engineers to assess and compare building designs and material choices at an early stage. The database contains North American (primarily Canadian) inventory data on structural assemblies and building envelope materials. The maintenance of building assemblies is also considered assuming a user-defined building lifetime. The results are presented by lifecycle stage or by assembly type in terms of primary energy use, global warming potential, solid waste emissions, pollutants to air and water, and natural resource use.

http://www.athenasmi.ca/

6.2 **Envest 2** (United Kingdom)

Envest 2 is a software tool developed by the Building Research Establishment in the United Kingdom for the **LCA and LCC of buildings**. Based on the geometry of the building and the element choice the tool estimates the operating energy and calculates the life cycle effects and costs. Environmental results are expressed in a single Ecopoint score. Ecopoints are derived from the impacts caused by a typical UK citizen, which corresponds to 100 Ecopoints.

http://envestv2.bre.co.uk/

6.3 **BEES** (U.S.)

BEES (**B**uilding for **E**nvironmental and **E**conomic **S**ustainability) is an **LCA based tool focusing on building products**, developed by the National Institute of Standards and Technology with support from the US EPA Environmentally Preferable Purchasing Program. BEES is a simple tool aimed at designers, builders, and product manufacturers. The tool enables direct product-to-product comparisons based on LCA and LCC. Environmental and economic performance are combined into a single score with weights specified by the user.

http://www.bfrl.nist.gov/oae/software/bees.html

7. RELATED APPROACHES

Although LCA covers a number of aspects, there are certainly limitations to this tool. Restricted to environmental issues, it usually doesn't cover economics and social issues. Having said that, there is a related tool "Life Cycle Costing", which can be combined with LCA to a certain extent to cover economics in a similar framework.

7.1 Life Cycle Costing - LCC

Life Cycle Costing (also called whole life cost) is a technique to establish the "total cost of ownership", i.e., the sum of all the costs associated with an asset or part thereof, including acquisition, installation, operation, maintenance, refurbishment, and disposal costs.

Life Cycle Cost compares the cost-effectiveness of alternative investments or business decisions from the perspective of an economic decision maker such as a manufacturing firm or a consumer.

Key similarities of LCA and LCC are that both use data on (Norris 2001):

- quantities of materials
- service life the materials could or will be used for
- maintenance and operational impacts of using the products and
- end-of-life proportions to recycling (and sale value) and disposal.

Key differences are:

- conventional LCC methods do not consider the process of making a product; they are concerned with market cost.
- LCA considers production
- Life-cycle costs are usually discounted over time, whereas environmental impacts are not discounted.

7.2 Whole Life Costing - WLC

Whole life costing is a term predominantly used in the building sector. The definition from the developing ISO Standard 15686-5, Buildings and constructed assets – Service life planning is:

"a tool to assist in assessing the cost performance of construction work, aimed at facilitating choices where there are alternative means of achieving the client's objectives and where those alternatives differ, not only in their costs but also in their subsequent operational costs."

8. SUMMARY AND OUTLOOK

Life cycle assessment is based on a systems approach and therefore avoids the shifting of problems from one life cycle stage to another or from one environmental issue to another.

LCA is a comprehensive tool which not only covers the whole life cycle of a building material, but also puts it into a systems perspective and looks at a range of different environmental impact categories. The definition of a functional unit which is the basis for any LCA focuses on a building component, e.g. a wall, rather than a building material, e.g. steel.

The results of an LCA can be used effectively in the building sector not only to improve the environmental performance of buildings, but also to influence policy making and provide quantitative fact based information for the development of ecolabels. On a company level the results can be used for product improvement and marketing. LCA data is currently used overseas in regulatory contexts and for subsidy schemes for home owners. Reliable LCA data on building materials is a prerequisite for this.

The basic methodology and expertise for undertaking LCA studies are available in New Zealand. A number of databases which have been developed overseas can be used as an template for developing New Zealand specific data. If representative regional data from New Zealand were available, it would be possible to adapt one of the international tools to the New Zealand conditions. Data on building materials themselves are critical for this.

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