

Life Cycle Assessment: Applications and implications for the greening of the South African construction sector

NAA LAMKAI AMPOFO-ANTI

CSIR Built Environment, Construction Competency Area, PO Box 395, Pretoria, 0001

Email: NAmpofoanti@csir.co.za

Abstract

The inordinate quantities of resources used and pollution released by construction products identify construction as a critical sector for a paradigm shift in consumption and production approaches. The Life Cycle Assessment (LCA) concept is an environmental management tool which emerged in the 1960s in response to concerns over the limitations of raw materials and energy resources. The concept is applied in decision-making at strategic, managerial and operational levels by policy-makers, industry and business to give an environmental perspective to products. Regulatory bodies in the developed countries are increasingly leveraging the LCA concept through new, science-based environmental policy instruments as a driver to stimulate sustainable patterns of consumption and production in the economy. LCA applications have been known and used in South Africa in a limited manner since the 1990s. However, no construction applications have emerged. Given the known contribution of construction products to environmental problems South African environmental policy does not preclude LCA applications to stimulate environmentally conscious decision-making in the construction sector. Potential LCA applications and the implications for greening South African construction products are discussed.

Key words

LCA applications, environmental policy, construction products, sustainable consumption and production.

1 Introduction

Industrial activity has traditionally comprised a linear process of inputs, namely, raw materials and energy; and outputs, namely, product(s), emissions and wastes. This approach, by its very nature assumes two things, namely, that there is unlimited supply of resources that provide inputs for the process, and that there is a bottomless pit that absorbs the outputs. This, unfortunately, is not the case (Macozoma, 2002) The consequences, which include Climate Change, have grave implications for the protection and preservation of the aspects

of the environment that society holds dear, namely, human health, ecological health and resource use.

The construction sector has a significant impact, both in positive and negative terms, on society and the environment. On the one hand, the sector plays an indispensable role through provision of shelter and other physical infrastructure and through job creation, both direct and indirect. On the other hand, it is estimated that the construction sector is accountable for the following consumption of natural resources (Edwards, 2002):

- Materials: 50% of all resources globally go into construction
- Energy: 45% of energy generated is used to heat, light and ventilate buildings and 5% to construct them
- Water: 40% of water used globally is for sanitation and other uses in buildings
- Land: 60% of prime agricultural land lost to farming is used for building purposes
- Timber: 70% of global timber products end up in building construction

As a huge polluter, the construction sector is also a significant contributor to annual greenhouse gas emissions and is the cause of 50% of all waste generated prior to recovery (Koroneos & Dompros, 2006). The explosive population growth of the last 100 years, and ongoing development aimed at infrastructure and service provision, place increasing pressure on the environment and identify construction as a critical industry sector for a paradigm shift in consumption and production approaches.

According to the environmental management guru Dr. David Suzuki the momentum to adopt sustainable approaches to environmental management has been building since 1962, with the publication of Rachel Carson's *Silent Spring* (American Association of Architects, 2007). A notable milestone is the Life Cycle Assessment (LCA) concept, a science-based tool which is designed to measure the environmental performance of products over their life cycle, from "cradle" (where the raw materials are extracted) to "grave" (where the product is finally disposed of)

(Schenck, 2006). More recently, the Johannesburg Plan of Implementation (JPOI), adopted by world environment ministers at the 2002 World Summit for Sustainable Development (WSSD), called for the adoption of tools, policies and assessment mechanisms based on life-cycle analysis to promote sustainable patterns of production and consumption and to increase the eco-efficiency of products and services (Hertwich, 2005).

This paper reviews LCA applications in general and suggests ways in which the lessons learnt can be applied to align environmental policy and practices in respect of South African construction products more closely with the imperatives of sustainable consumption and production.

2 Main characteristics of LCA

2.1 LCA history

The LCA concept emerged in the 1960s. The first LCA study, then known as a Resource and Environmental Profile Analysis (REPA), was commissioned by the Coca Cola Company, USA in 1969. The study compared glass and plastic coke bottles by quantifying the raw materials and energy used, and the releases to the environment from the manufacturing process for each container. The study resulted in a switch in packaging from glass to plastic bottles (USEPA, 2006).

The development and spread of applications was possibly driven by public concerns over the limitations of raw materials and energy resources arising from the seminal *Limits to Growth* (1972) and the Oil Crisis of the 1970s. The concept became well-known and used amongst environmental policy-makers. Private business and industry sectors also used LCA data internally to give an environmental perspective to their products (Baumann & Tillman, 2004).

Early LCAs were characterised by a high degree of divergence in methods and results which created uncertainty (Gabathuler, 2006) and a great deal of scepticism (Baumann & Tillman, 2004). A process to standardise LCA methodology under the International Organisation for Standardisation (ISO) resulted in publication in the late 1990s of the current four-step methodological framework, namely, the ISO 14040 Series *Environmental Management – Life Cycle Assessment*. The 14040 Series was updated by ISO in 2006.

2.2 LCA definition

Life Cycle Assessment (LCA) is an environmental management tool for compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (SANS 14044, 2006). There are two categories of inputs, namely, environmental inputs (raw materials and energy) and economic inputs (products, semi-finished products or energy from other processes). Similarly, there are two kinds of outputs, namely, environmental outputs (emissions to air, water and soil) and economic outputs (products, semi-finished products or energy) (Friedrich & Buckley, 2002). The term “life cycle” refers to the major activities in the course of the lifespan of the product from the acquisition of raw materials to manufacturing, use/reuse/maintenance and waste management (USEPA, 2003). LCA does not necessarily attempt to quantify actual environmental impacts associated with a product. Instead, it seeks to establish a linkage between a product and potential points of impact in the environment.

2.3 LCA principles

According to the international standard *Environmental Management – Life Cycle Assessment*, there are seven guiding principles for LCA, namely (SANS 14040, 2006):

- Life cycle perspective - LCA is distinguished from other science-based environmental management tools in that it considers environmental impacts of economic activity along the whole life cycle whereas the purpose of other frequently used tools, for instance, Environmental Impact Assessment (EIA) and Risk Assessment (RA) is to resolve environmental issues in respect of a specific plant or facility at a specific location. The systems perspective of LCA avoids problem shifting from one life cycle stage to another, from one type of problem to another and from one location to another (UNEP IECPP, 1996).
- Environmental focus - LCA is applied qualitatively, to analyse the environmental aspects of a service, for instance, policy formulation. Alternatively, it is applied quantitatively, to analyse the environmental impacts of a specific product, for instance, a building material. Economic and social aspects and impacts are typically outside the scope of an LCA.
- Relative approach and functional unit - LCA is

a relative approach, which is structured around a functional unit. This functional unit defines what is being studied.

- Iterative approach - LCA relies on an iterative technique whereby each subsequent phase uses the results of the previous phase, contributing to consistency of study results.
- Transparency - due to the inherent complexity of LCA, transparency is an important principle which assures proper interpretation of the results.
- Comprehensiveness - LCA considers all aspects of the environment comprising human health, ecological health and resource use.
- Priority of scientific approach - LCA gives priority to scientific decision-making, but where neither a scientific basis exists nor a justification based on other scientific approaches is possible, then appropriate decisions may be based on value choices (Fava , 2005).

3 LCA applications

LCA is used in various ways by a wide range of societal actors including economic regions, national governments, industry, business, NGOs and consumers to integrate environmental concerns into economic activity. The UNEP/SETAC Life Cycle Initiative was launched in 2002 in response to the endorsement by the Global Environmental Ministerial Forum of a “life cycle economy” supported by LCA-based environmental policy (Aloisi de Larderel, J., 2006). The broad aim of the Life Cycle Initiative is to enable users around the world to put the LCA concept into effective practice at three levels of detail. The Life Cycle Approaches defined by the initiative comprise Life Cycle Thinking (LCT), Life Cycle Management (LCM) and Life Cycle Assessment (LCA) (UNEP/SETAC, 2008).

Table 1: LCA applications according to LCA Approach

LCA Approach	User type	Area of application	Examples
Life Cycle Thinking (conceptual LCA, qualitative data)	Economic regions National governments Other regulative bodies	Product-oriented policy	Green procurement Integrated product policy (IPP) Extended producer responsibility (EPR) Eco-labelling Cleaner Production (waste minimisation, pollution prevention)
Life Cycle Management (LCM) (simple LCA, qualitative data)	Industry and other commercial enterprises NGOs	Product-oriented company policy	Green procurement Design for Environment Cleaner Production
Life Cycle Assessment (LCA) (Detailed LCA, quantitative data)	Industry and other commercial enterprises NGOs	Product-oriented decision support	“Hot spot” identification Product design and development Product comparisons Process development and optimisation Marketing (eco-labelling) To meet policy demands

3.1 Life Cycle Thinking (LCT)

Life Cycle thinking supports product-oriented decision-making at a strategic or conceptual level. The essence of LCT is that key actors in a product value chain cannot strictly limit their responsibilities to those phases of the life cycle of a product, process or activity in which they are directly involved. According to SETAC it expands the scope of their responsibility to include

environmental implications along the whole life cycle (Tan et al. , 2002). The integration of LCT into company policy establishes a “chain of custody” which stimulates product stewardship in industry sectors thereby responding to consumer demands for environmental protection.

National governments and economic regions in the developed countries are increasingly leveraging

their purchasing power through environmental policy instruments rooted in LCT to stimulate societal actors along the value chain to improve the environmental performance of products, processes and services (UNEP/SETAC, 2005). Demand-side mechanisms applied by regulatory bodies include Integrated Product Policy (IPP) and green procurement strategies.

As opposed to a specific product policy which addresses a particular environmental problem IPP provides a framework for integrating a number of product-focussed concepts, tools and programmes, for instance, green marketing, green procurement, extended producer responsibility (EPR) and design guidelines and standards for products and processes to promote Design for Environment (DfE) and Cleaner Production (CP). IPP is applied within the European Union (EU) and promoted by the OECD countries and the UN Commission on Sustainable Development.

Examples of green procurement initiated by regulatory bodies are (Fava, 2006):

- The United States Environmental Protection Agency (USEPA) Environmentally Preferable Purchasing (EPP) programme a US federal-wide programme which encourages the use of products and services which have a reduced effect on human health and the environment when compared with competing products or services which serve the same purpose.
- The European Union Product (EuP) Directive, applicable to any product using energy to perform the function for which it was designed.

3.2 Life Cycle Management (LCM)

Life Cycle Management is an integrated framework of concepts, programmes and techniques for improving organisations and their respective goods and services. An LCM framework is flexible and can address a wide range of improvements to technological, economic, environmental and social aspects (UNEP/SETAC, 2005). LCM encompasses a number of tools based on the life cycle concept, for instance, Life Cycle Inventory (LCI) and Life Cycle Costing (LCC). LCM is mostly applied in industry for purposes of product development, supply chain management and green procurement including material specifications and material restrictions. A key application of LCM in the context of the EU is Eco-design also known as Design for Environment (DfE). Typically, companies respond

to product take-back legislation, for instance, the EU's end-of-vehicle life policy by designing their products for ease of disassembly, ease of recycling and free of hazardous substances and materials (Five Winds International 2007). The main users of LCM are the electrical and electronic goods, motor vehicles and packaging sectors (Baumann & Tillman, 2004). LCM is used as a tool by the Mercedes Car Group to improve the environmental performance of various models through DfE strategies (Finkbeiner & Hoffman, 2006).

3.3 Life Cycle Assessment (LCA)

A product-focussed regulatory environment is a primary driver for operational level or quantitative LCA applications. An LCA or LCI study provides the quantitative data to facilitate compliance with policy, meet chain of custody requirements and pursue own goals in respect of product stewardship and gaining a competitive edge in the green market. To comply with legislation, downstream companies typically resort to product development. This may entail improvement of an existing product or design of a fundamentally new product through DfE strategies. Upstream companies in turn discharge their chain responsibility to supply green materials and components by optimising production processes through Cleaner Production (CP) strategies.

Environmental marketing, also known as green marketing or ecological marketing refers to the process of selling products or services on the basis of environmental benefits. It is an essential component of product-focussed environmental policy which facilitates public dissemination of the "environmental cleanliness" of a product. A key spin-off for companies is an improved image and market. Environmental marketing includes a wide range of activities but essentially takes two forms, namely, business to business communication; and business to consumer communication. To avoid the proliferation of non verifiable and misleading claims; and encourage the demand for and supply of environmentally preferable products the ISO established the 14020 Series of documents - *Environmental labels and declarations*. The series makes provision for three principal types of labels and declarations, namely:

- Type I Environmental labelling identifies the overall environmental preference of a product

or service within a specific product category based on life cycle considerations (GEN, 2008). A number of pre-determined LCA-based criteria are used to assess a product prior to award of a Type I label. To ensure credibility of labelling programmes, the label is awarded by an impartial third-party (SANS 14024, 1999). Type I labels are typically awarded to products approved by an eco-labelling programme operated at national or regional level, for instance, Green Seal (USA), Good Environmental Choice (Australia) and the European Commission's DG Environment.

- A Type II self-declared environmental claim can be made on packaging labels through various means including but not limited to product literature and electronic media such as the internet (SANS 14021, 1999). As the data on which a Type II claim relies does not have to be LCA-based there is no certainty that such claims lead to reduced environmental impact (Ritchie, 2006). Examples of applications in the US construction sector include the USEPA's Energy star programme and the Resilient Floor Covering Institute's FloorScore programme.
- A Type III environmental declaration is also known as Environmental Product Declaration (EPD). It provides information regarding the environmental aspects of products and services based on information from quantitative LCA studies. (GEDnet, 2008). An EPD typically provide data per life cycle stage, for instance, content of chemicals subject to regulation or recommendations for maintenance and disposal. The label is awarded by an impartial third-party (SANS 14025, 2006). Leaders in Type III declarations are the Building Research establishment (BRE) of the United Kingdom and Scientific Certification Systems (SCS), the USA's first science-based programme for independently verifying the accuracy of environmental claims in respect of products (Ritchie, 2006). An EPD provides building professionals with a new and precise method of determining the environmental performance of building designs.

4 LCA applications in construction

The construction sector provides the physical infrastructure which constitutes the built environment, amongst others, buildings, roads, railways, ports and bridges. Although the construction supply chain comprises a complex

network of social actors, the decision makers who have a significant influence on the environmental performance of construction products can be classified into two broad groups, namely, upstream companies (process and manufacturing sectors), responsible for the production of building materials and components; and downstream companies (general and specialist contractors and built environment professionals), who are involved in the planning, design, on-site construction and commissioning of built infrastructure.

Despite the long history of LCA applications in industry construction related applications only gained ground in the last decade. The applications identified in the literature can be broadly classified into three groups, namely, construction material and component applications, whole building applications and LCA tools.

4.1 Construction material and component applications

The findings of LCAs conducted on the most commonly used construction materials, for instance, cement, steel, concrete, copper and glass confirm that construction materials production is a very energy intensive process (Koroneos&Dompros, 2006; WBCSD, 2007). Acidifying emissions, in particular, carbon dioxide make up the biggest releases to the atmosphere. For instance, the cement industry accounts for 5% of global man-made carbon dioxide emissions annually (WBCSD, 2007). In most instances 60-80% of the environmental impacts of a construction material are incurred during design and production processes and activities (Ortiz et al.). Materials production is also the most important contributor of emissions to water and land, including toxic releases (Athena EIE, 2008). As compared to construction materials, data which establish an environmental profile of construction components such as doors and windows are in the literature.

Most studies on construction materials have focussed on energy consumption through the evaluation of embodied energy. Embodied energy is the energy used in the processing of raw materials as well as the manufacturing and installation of materials and products in buildings (Treloar et al., 2001). The outcomes of such studies are however misleading because in reality a material or component will impact on the environment as part of a complex building system.

It is therefore more relevant to consider environmental impacts over the entire life cycle (Lloyd et al.); (Trusty, 2008a). Also, selection of a product on the basis of low embodied energy overlooks potentially more hazardous emissions associated with manufacture of that product; and passive solar principles used together with envelope materials of a high mass have been shown to offset the embodied energy of the building envelope.

The typical focus of improvement options is to reduce embodied energy. Two approaches were identified in the literature, namely:

- Waste management strategies which aim to avoid production-related emissions (and thereby the use of virgin raw materials) through reuse and recycling. A case study suggests that reuse strategies have great potential and could in future reduce heating energy demand in buildings by up to 70% (Ortiz et al.). However, reuse may not be suitable for certain materials, for instance, reused bricks may lack the strength of new bricks therefore structural applications should be avoided (USEPA, 2003). Recycling is used extensively for concrete and steel, two of the most common construction materials by weight but given the history of cheap resources and low waste disposal costs, the potential of reuse and recycling is insufficiently explored in construction.
- Design of radically new materials with a lower environmental impact than conventional materials, for instance, those made from a renewable resource or those based on nanotechnology. It is however advisable to investigate the environmental risks of such new technologies prior to their use (Ortiz et al.).

4.2 Whole building applications

The LCA of a whole building is a complex, time consuming and costly process requiring investigation of a large number of building elements, for instance, the roof, envelope structure or mechanical and electrical services. Similar to the approach adopted for LCAs of materials and components whole building LCA studies have focussed on energy consumption and associated emissions of greenhouse and acidifying gases. One study which extended the scope of analysis to include the additional impact categories ozone depletion, eutrophication and human toxicity still

confirmed the dominant role of energy consumption in the environmental profile of buildings (Adalberth et al., 2001). The results from whole building LCAs confirm that a building has five generic life cycle stages, namely, raw materials acquisition, manufacturing, on-site construction, use/maintenance/renovation and waste management. The life cycle stages contribute to the environmental impacts of a building as follows:

- The use/maintenance/renovation life cycle stage may last 50-100 years and has the highest environmental impact. It is the largest contributor to energy consumption (at least 70%) and associated emissions, for instance, carbon dioxide. (Adalberth et al., 2001; Blanchard & Reppe, 1998; Junnila et al., 2006).
- The manufacturing stage has the second highest environmental impact in the building life cycle. This is attributable to energy consumption and atmospheric emissions associated with the production of conventional construction materials, for instance, concrete, steel, copper and glass (Blanchard & Reppe, 1998; Junnila et al., 2006).
- The on-site construction and waste management stages contribute the least to the environmental impact of buildings (Blanchard & Reppe, 1998; Junnila et al., 2006).

The total life cycle environmental impacts of buildings can be reduced considerably. In one instance, a factor of 2.8 was achieved. Environmentally conscious decision-making is however required at the design stage and requires selection of materials in consideration of embodied energy and rate of replacement/maintenance; and use of energy efficient appliances (Blanchard & Reppe, 1998). Some of the environmental impacts associated with the first and last life cycle stages, namely raw materials acquisition and waste management include loss of habitat and biodiversity and exposure of humans and ecological systems to contaminants. Inventory and assessment of these two life cycle stages is however excluded from the majority of studies.

4.3 Construction LCA tools

The inherent complexity of LCA demands tools to simplify the process and encourage the uptake Life Cycle Approaches by non-LCA experts. In addition to commercially available LCA software packages,

construction-specific tools have been developed and comprise building rating and certification systems, whole building tools and tools for the assessment of construction materials components.

4.3.1 General LCA software tools

General LCA software tools are multipurpose in nature and are therefore used extensively across all industry sectors. The software can be used in construction applications to assess environmental performance of construction materials, components or whole buildings, provided the appropriate LCI data are selected and incorporated. The tools are however intended for use by LCA experts (Lloyd et al.).

4.3.2 Building rating and certification systems

Building rating and certification systems prescribe green practices for reducing the environmental impacts of a building. Today's high-performance green buildings are a significant improvement over the conventional buildings of the past. They consume significantly less energy, materials and water; and significantly improve the quality of the built environment (Kibert, 2007). However, benchmarking what is "green" on the basis of prescribed lists of "green" features allows one environmental problem to be solved while creating or avoiding other problems, amongst others:

- Recycling can save landfill space, but the process of recycling a given product may take more energy and adversely affect air quality more profoundly than would production from virgin resources (Trusty, 2008b).
- Energy efficiency strategies are placed high on the environmental agenda yet the important issue of closing materials loops in construction, perhaps the most difficult technical problem of sustainable construction, is barely addressed (Kibert, 2007)
- There are highly rated buildings that perform up to their billing, but there are also highly rated buildings that do not perform well at all – a recent post-occupancy study of several LEED buildings illustrates some of the problems. Of four new office buildings in the sample, only one had actual energy usage better than the modelled usage, while the other three performed worse than expected (Trusty, 2008a).

Given increasing pressure from new, science-based environmental policy there is now growing support in construction circles for the notion that certification should focus on true environmental performance measures, such as climate change or human toxicity giving professionals the flexibility to assess and decide on trade-offs. Green standards and rating systems which rely on LCA-based credits include the UK's Building Research and Establishment Environmental Assessment Method (BREEAM) and Green Globes (North America). The US Green Building Council is studying approaches to incorporate LCA into LEED.

4.3.3 Whole building tools

A whole building tool, for instance, the Athena Environmental Impact Estimator (EIE) (USA and Canada) is applied at the concept design stage of a project. The aim is to compare the potential environmental impact of different design options or evaluate how substituting different materials or components in a building design affects its overall environmental impact (Lloyd et al.). Whole building tools may either be applied at the level of a whole building or assembly. The comparison is done in the context of structural and envelope systems. A whole building tool does not require any LCA expertise and is intended for use by built environment professionals for quick assessments.

Table 2: Construction LCA tools

Tool name	Tool category	Application
SimaPro (Netherlands)	General LCA software	For detailed LCAs of specific building materials, components and designs
GaBi (Germany)		
Umberto (Germany)		
TEAM (France)		
BEES (USA)	Building-specific software	Applied at specification stage for Selection of materials and components
Athena Environmental Impact Estimator (EIE) – USA/ Canada	Building-specific software	Applied at design concept stage for preliminary assessment of whole buildings or assemblies
BRI LCA (energy and CO2) Japan		
EcoQuantum Netherlands		
Invest (UK)		
Green Guide to Specifications (UK)		
LISA (Australia)		
BREEAM (UK)	Building-specific software	Standards and rating systems - certification and labeling of whole buildings
GBTool (International)		
Green Globes (Canada/USA)		

4.3.4 Tools for assessment of construction materials and components

Tools for assessment of construction materials and components are complementary to whole building tools and are intended for use by built environment professionals. A typical tool incorporates generic datasets which are representative of average technology in the given nation or region. International usage is therefore not advised. Such tools provide information at the specification stage of a project to guide selection of materials and components which have the least environmental impacts (Trusty, 2008b). Some are combined with other features, for instance, Life Cycle Costing (LCC) to facilitate the identification of explicit trade-offs. An example is the Building for Environmental and Economics Software (BEES), USA.

5 Status of LCA in South Africa

5.1 Legislative and policy context

LCA approaches provide a systematic opportunity to anticipate environmental problems and their solutions along the whole product life cycle. This approach is in line with post apartheid environmental policy which advocates the adoption of a risk-averse and cautious approach to development thereby obviating the need for end-of-pipe treatments (Department of Environmental Affairs and Tourism (DEAT), 2000). The policy position is informed by the Agenda 21 blueprint on Sustainable Development; and mandated under chapter 2, Section 24 of the Constitution Act 108 of 1996 which compels government to put in place “reasonable legislative and other measures” to protect the environment for the benefit of current and future generations.

The overarching policy framework, set out in the *White Paper on Environmental Management Policy for South Africa*, 1998; the *National Environmental Management Act (NEMA)* 107 of 1998; and the *White Paper on Integrated Pollution and Waste Management, 2000* promote the use of science-based tools in environmental policy and decision-making. Policy provisions which have implications for the future direction of environmental management in industry are the requirement to assess environmental problems on the basis of Environmental Impact Assessment (EIA) tools; and a stipulation which holds waste generators responsible for their waste material with no time limit. The ISO 14040 series on LCA has been accepted into the environmental management framework for South Africa since 1998. There is however no legal requirement to use LCA.

A key environmental issue of concern for South Africa and the global community is the nation's contribution to the phenomenon of climate change. Classified as one of the top ten air polluters, South Africa accounts for more than 40% of greenhouse gas (GHG) emissions on the African continent (Du Plessis et al., 2003). Generation of energy from abundant coal reserves and a proliferation of energy intensive industry sectors, including construction accounts for at least 80% of emissions. Given that South Africa is vulnerable to the projected impacts of climate change government has taken steps to demonstrate

effective strategies for achieving emissions reductions. These include:

- Ratification of the Kyoto Protocol in 2002
- Alignment of air quality management provisions with modern trends through the Air Quality Act 39 of 2004.
- Formulation and roll-out of an Energy efficiency Strategy which aims to achieve demand reduction by 12% by 2015 (DME, 2005).
- Formulation of a science-based Long-term Mitigation Scenarios (LTMS) aimed at transitioning the country to a climate resilient and low-carbon economy and society by 2050 ((Scenario Building Team , 2007)
- Investigation of a carbon tax mechanism to be implemented after 2012, possibly with mandatory elements (Creamer, 2008).

5.2 Status of LCA applications

As an environmental management tool the concept of LCA has been known and used by research institutions, academic institutions and industry since the early 1990s. Despite the strong South African policy position on pollution prevention there is generally a low level of legal enforcement by authorities and therefore a low priority attached to the environmental performance of industry sectors (Brent et al., 2002).

The primary driver for adoption of cleaner technologies is the demand for LCA-type product data on exports to the developed nations (Friedrich & Buckley, 2002); (Brent et al. , 2002). Specific South African surveys to examine the motivating factors for uptake of Cleaner Production further confirmed that whereas smaller companies were cost and production driven and less likely to integrate environmental concerns into their operations the larger companies were the most likely to adopt cleaner strategies(Hanks & Janisch , 2003). Researchers based at the Universities of Pretoria, Natal, Cape Town and Witwatersrand have also engaged in the development and application of LCA techniques in response to needs in industry; for purposes of producing graduates skilled in LCA; and to produce research publications (Brent et al., 2002).

At the analytical level, LCA has been applied mainly in a descriptive or retrospective sense to document the environmental impacts and aspects of existing products and processes in order to identify opportunities for improvement. Change-

oriented or consequential studies conducted for DfE purposes are rare. The water industry is the most prolific user of data from descriptive studies and has conducted a number of studies since 2001, for instance, a comparative study of two water treatment plants to select the best available technology. Examples of LCA applications in South African industry include (Friedrich & Buckley, 2002):

- A full gate-to-gate LCA of two paper products funded by Mondi Ltd.
- An LCA study carried out by Enviroserv to investigate the environmental problems associated with two of their products, namely, one cosmetic and one shoe polish brand.
- An LCA study carried out by Natal Portland Cement to better understand the environmental impacts of cement in the South African context.

At the level of LCM applications there is extensive research in the context of the manufacturing sector aimed at identifying country-specific performance indicators for assessing the environmental impacts associated with the suppliers.

Due to the complexity of LCA, and the lack of country-specific LCA methods South African LCA practitioners generally rely on published LCIA methods, for instance, the CML Method (Netherlands), Ecopoints (Switzerland), Eco-indicator 95 and 99 (Netherlands) and EPS (Sweden) (Brent et al. , 2002) . However, South African environmental conditions differ significantly from European conditions therefore the data embedded in the software may be representative of the life cycle under study, but reliability is problematic (Brent & Hietkamp, 2003). Moreover, environmental impacts due to water and land usage are critical in the South African context but are barely addressed by the European methods

5.3 Constraints to LCA applications in South Africa

There are two types of constraints associated with applications of LCA in the context of South Africa. The first type of constraint is general and affects LCA practitioners internationally, namely (Friedrich et al., 2007).

- Whereas energy consumption is generally well documented, there are often severe data gaps in respect of other resource use.
- In most cases environmental impacts due to water consumption is not included in a study.

- Land use and biodiversity issues are not considered because internationally there is as yet no consensus on how to model these impacts in the inventory phase of a study.
- Toxicological impacts on human health and ecosystem health are considered but there are data gaps.
- Impacts such as global warming, ozone depletion, acidification and photo-oxidant formation are included in most studies. However data on eutrophication (aquatic) is usually incomplete.
- A number of emissions are classified as “particulate emissions” making differentiation of the contributory gases impossible.
- Policy implementation in the post-apartheid era is dominated by the socio-economic aspects of sustainable development, for instance, provision of basic infrastructure, delivery of housing and schools or compliance with BBBEE requirements.
- Legislation, regulation and by-laws influencing design decision-making in the construction sector do not require key industry decision-makers such as building designers, contractors, suppliers and manufacturers to address the key environmental issues of concern in the industry supply chain, for instance, resource depletion potential, air pollution or excessive generation of construction and demolition waste.
- The conventional design framework and principles employed in the built environment is concerned with thermal comfort, acoustics, weather exclusion, cost, health and safety; and not with environmental protection issues.

The second type of constraint is specific to the South African context, namely:

- The reluctance of South African companies to provide LCA type data (Friedrich et al. , 2007).
- The relevance of LCA methodologies developed overseas to the local environment, in particular, the available methods make no provision for assessing impacts due to water and land availability; and there is no regional or local characterisation factors developed for South African conditions (Brent , 2004)). The methods are also not relevant for water salinisation which is an environmental issue of strategic concern in the South African context (Leske&Buckley, 2003).

South African research into methodological issues, that is, creation of a separate impact category for water salinisation; and development of a country-specific life cycle impact assessment method are aimed at eliminating some of these constraints in order to make LCA more efficient and meaningful in the local context.

5.4 Status of environmental management in construction

For almost two decades, the LCA concept has been applied in some South African industry sectors in support of environmental decision-making. However, an extensive literature search could not locate any LCA applications in the context of the South African construction sector. There are three broad reasons why the environmental performance of buildings has not enjoyed a high priority in the South African construction sector, namely:

With the increasing threat of climate change, and the mounting evidence of how the products of the construction sector contribute to this phenomenon, the South African construction sector is now under pressure to improve its environmental performance. There are a number of green building initiatives already responding to this challenge.

5.5 Green building initiatives

- The Green Building Council of South Africa (GBCSA) was founded in 2007 and aims to develop and operate South Africa’s first green building rating and certification system. Modelled on the Australian Green Star system, the Green Star SA rating tools will be developed through a consensus-based process for various building types. The first tool was released for trial and public comment in July 2008 (GBCSA, 2008).
- Government is leading by example in the area of retrofitting of existing buildings. Driven by the Department of Minerals and energy (DME), the initiative aims to retrofit 106 000 public buildings in order to increase energy efficiency by up to 70%; decrease potable water consumption by up to 80%; and lower discharge to sewers by up to 70%. Over 100 buildings in Gauteng, Western Cape and Free State have already been completed (Van der Merwe, C., 2008).

- The Cities for Climate Protection Campaign, funded by the US Agency for International Development (USAID) is a worldwide network of over 500 local authorities that have demonstrated a commitment to mitigating climate change through local action. The eight South African cities currently involved in this global campaign are Buffalo City, Cape Town, eThekweni, Johannesburg, Potchefstroom, Saldhana Bay, Sol Plaatje and Tshwane (DEAT, 2005).
- It is consensus-based, thus scoring is based on well-established construction sector perceptions on environmental management, and not scientific facts.
- It is fragmented, as it only considers the activities of the professional services sub-sector, ignoring the substantial impacts associated with the other two sub-sectors in the construction supply chain, namely, materials manufacturers and suppliers; and general and specialist contractors.

6 Lessons learnt

It is now known that the main sources of environmental deterioration by industry sectors and business are the products and services produced. The precursor for lowering the environmental burdens of construction while maintaining sustainable growth is the greening of construction products. Life Cycle Approaches, namely, LCT, LCM and LCA provide such an approach.

A shift has occurred in environmental policy and management practices. Firstly, there is an indication that management of the complete product life cycle may become entrenched in environmental legislation as countries and economic regions roll-out new science-based legislation, rooted in Life Cycle Approaches, to drive their industry sectors and national economies in a more sustainable direction. Secondly, other industry sectors have taken the lead by moving away from mere compliance with regulation to adopt product stewardship strategies such as Design for Environment (DfE) or Cleaner Production (CP).

South Africa is known as a huge air polluter internationally. On the one hand, a proliferation of energy intensive industries, including construction, contributes to the worldwide problem of global warming and acidification. On the other hand, the nation is vulnerable to the predicted impacts of excessive air pollution, namely, Climate Change. Provisions for environmental protection, as set out in The Constitution Act 108 of 1996 and the NEMA Act provide a mandate for the South African construction sector to take the lead in environmental stewardship. The recent adoption of green initiatives, in particular, the GBSA's Green Star rating system is not sufficient because:

- It is voluntary, attracting only those who want to engage with product stewardship.

LC Approaches provide a number of opportunities for improving the environmental performance of the South African construction sector.

At the broader industry level Life Cycle Thinking (LCT) can provide guiding principles for integrating the product stewardship strategies of the downstream supply chain (professionals and contractors) with the strategies of the upstream supply chain (manufacturers and suppliers) to avoid problem shifting. Other strategic considerations include:

- Development of a publicly available Life Cycle Inventory (LCI) database to ensure wide dissemination of high quality country-specific data and encourage uptake of life cycle approaches.
- Updating of pre-1994 legislation, regulation and by-laws to align with Constitutional provisions.

Life cycle management (LCM) can provide an integrated framework for whole life cycle management in the construction sector:

- The Built environment professions sub-sector will need to use Design for Environment (DfE) principles. Design options, building materials and components will be selected on the basis of quantitative environmental data. Designers need to consider and integrate environmental concerns such as construction and demolition waste minimisation, possibilities for re-use, recycling or disassembly at the design concept stage.
- The materials manufacturing sub-sector will need to use Cleaner Production (CP) strategies which are already used by other industry sectors, for instance the textiles industry. Manufacturers and suppliers need to make information on the environmental aspects of their products easily available
- The contracting sub-sector will need to purchase materials and components on the basis of product environmental data.

The LCA-based action agenda outlined in Table 3 is proposed to shift the South African construction sector onto a path much closer to the ideals of sustainable consumption and production. The following key priorities and objectives are defined to drive the proposed action plan, namely:

- Avoid problem shifting from one sub-sector to another or from the upstream life cycle to downstream life cycles by entrenching LCT or “chain of custody” in the construction supply chain.
 - Adoption of appropriate LCM approaches, strategies and techniques by each construction sub-sector.
 - Development of appropriate LCA-based decision support tools for all actors in the construction supply chain; and use of appropriate LCA-based communication tools to enable customers to make informed choices in respect of the environmental impacts of a product, process or service.
- Formulation of an LCM for each sub-sector to manage the significant environmental impacts over which it has direct control.
 - Improve environmental performance of own products, processes and services by influencing decision-makers in other sub-sectors.
 - Conserve non-renewable materials, reduce waste from operations, increase recovery of waste and ensure responsible disposal.
 - Increase energy efficiency through responsible energy sourcing and use of energy efficient technologies.

Table 3: Proposed framework for Life Cycle Approaches in construction

Construction sub-sectors	LCA applications			Enabling legislation, policy programmes and policy instruments
	LCT (Strategic level)	LCM (Procedural level)	LCA (Operational Level)	
Built environment professional consulting	Adoption of life cycle perspective by all stakeholders	<p>Education: integration of environmentally oriented modules into BE curricula to increase knowledge and competence around environmental protection.</p> <p>Design principles: Design for Environment (DfE) – design to increase resource efficiency; decrease costs; and optimise end-of-life management by prioritising re-use, recycle or composting.</p> <p>Green procurement: integration of environmental concerns into tendering practices and processes.</p> <p>Green marketing: voluntary environmental declaration programme for physical infrastructure</p>	<p>Decision support tools:</p> <ul style="list-style-type: none"> -Quantitative assessment tools for whole buildings, components and building materials. - Publicly available LCI database - Green specification manual <p>Communication tool:</p> <ul style="list-style-type: none"> - Performance-based rating systems 	<p>Legal instruments</p> <p>Constitution, Act 108 of 1996</p> <p>NEMA Act</p> <p>NBR Act 103 of 1977 (performance-based revision required)</p> <p>PPPFA Act of 2000</p> <p>SAQA Act of 1995</p> <p>Professions' Acts of 2000</p> <p>CBE Act 43 of 2000</p> <p>Policy programmes</p> <p>IPP (incorporating EPR, environmental labelling, environmental declarations and environmental certification systems and green procurement)</p> <p>Financial instruments:</p> <p>Carbon taxes</p>
Construction contractors		<p>Education: skills training to raise awareness of environmental issues</p> <p>Construction principles: Cleaner Production (CP) conserve resources and reduce toxic emissions and wastes at source</p> <p>Integrated waste management (IWM) – optimise management of construction and demolition wastes by prioritising re-use, recycling and composting.</p> <p>Green procurement: purchasing of building materials, components and construction equipment on the basis of environmental data.</p> <p>Green marketing: voluntary environmental certification programme for construction companies</p>	<p>Decision support tools:</p> <ul style="list-style-type: none"> -Publicly available LCI database -Product environmental information data sheets of building materials and components <p>Communication tool:</p> <ul style="list-style-type: none"> -Environmental certification systems for construction companies 	
Construction materials manufacturing		<p>Education: skills training to raise awareness of environmental protection and conservation.</p> <p>Design principles: Cleaner Production (CP) conserve resources and reduce toxic emissions and wastes at source</p> <p>Integrated waste management (IWM) – optimise management of product and process emissions and wastes by prioritising re-use, recycling and composting.</p> <p>Green procurement: purchasing of building materials, components and construction equipment on the basis of environmental data</p> <p>Green marketing: voluntary environmental certification programme (companies) and environmental labelling and declarations (products and processes).</p>	<p>Decision support tools:</p> <ul style="list-style-type: none"> -Product and process-specific LCI data. -Publicly available LCI database <p>Communication tools:</p> <ul style="list-style-type: none"> - Type III environmental labelling scheme for building materials and components -Environmental certification systems for manufacturers and suppliers 	

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