Life Cycle Costing and the Environment

Gjalt Huppes
Martijn van Rooijen
René Kleijn
Reinout Heijungs
Arjan de Koning
Lauran van Oers

CML, April 2004

Report of a project commissioned by the
Ministry of VROM-DGM
for the
RIVM Expertise Centre LCA

Zaaknummer 200307074

Executive Summary

From very different backgrounds, costs have been related to functional performance over the life cycle, as Life Cycle Cost. Optimal public budget allocation over the life cycle and optimal business performance belong to one main group, here named budget LCC. Optimal allocation of production factors in society when selecting projects is a second domain, that of Cost Benefit Analysis. CBA has developed in a welfare theoretical context and also takes a life cycle point of view. Life Cycle Assessment, LCA, a method for assessing broad environmental performance, requires its adjoining cost measurement method in practical decision support. No standardised cost methods have been developed yet. Budget LCC and CBA-type LCC have a modelling set-up which differs fundamentally from most LCAs: quasi-dynamic modelling versus steady state modelling. So, three distinct approaches may be discerned: budget-LCC, CBA-LCC, and LCA-LCC. The central goals of this paper are to define approaches and methods, and their relations, and to see how they might best be aligned.

Next, the question is how fundamental the differences between approaches and methods really are. An analytical framework is developed along a number of main dimensions related to cost - and in principle similarly to benefits that in many instances cannot easily be distinguished from negative costs. These dimensions are:

- which types of cost are taken into account, ranging from out-of-the-pocket budget cost to highly abstract social cost;
- whose cost are taken into account, ranging from specific firms or groups, to society at large, as global society;
- the modelling set-up, especially as related to time, with quasi-dynamic modelling and steady state modelling as main examples;
- the method of cost aggregation, with average cost, net present value, and annuity as main methods.

Using a stylised example, the differences and similarities are shown.

Having answered how methods are related, the final question of how methods might be selected and aligned is answered in a tentative way. Firstly, all methods involving several groups of cost bearers, but not full society, seem open to fundamental arbitrariness, as the example may show. Secondly, it appears that quasi-dynamic cost models can be transformed into steady state models, giving a direct alignment to environmental LCA. The converse is not so easily possible. Third, however, cost integration methods from budget LCC and LCA-type LCC can be chosen which are directly comparable to the average cost per unit of function of steady state LCA. It involves first aggregating the cost in time into their Net Present Value, and next transforming this outcome into an eternal annuity. This seems a major addition to our toolbox for combined economic and environmental analysis. Fourth, integrating long-term environmental effects by monetising and discounting cannot now be done in a well reasoned way. Such effects, or indicators involved like Global Warming Potential, best be specified separately, at least for the time being. Underlying differences between cost approaches remain. A basic one is related to the market discount rate, inflation corrected, in budget LCC, versus the social time preference discount rate, in CBA-type LCC, with possible corrections eg for risk and income changes. These different views on cost both are legitimate and may result in different well defined adjoining cost outcomes.

Contents:

1. Introduction

1.1. What is LCC?

Life Cycle Costing (LCC) is a method of calculating the total cost of a product (covering both goods and services) induced throughout its life cycle. It is an analytical tool that belongs to the group of the life cycle approaches. Life cycle approaches are the tools, programmes and procedures, which help making decisions based on the life cycle of products (see UNEP-SETAC 2004[1]). LCC is often used for decisions about the design, development and purchase of these products, processes, or activities, and the public policies related to them. As the name suggests two terms are of prime relevance in LCC: *life cycle* and *costing*.

A life cycle consists of a number of stages, which depend on the goals and scope of the problem, and the method of investigation chosen. A few examples of life cycle stages are:

- Design, acquisition, consumption, disposition (ComEd 1996[2])
- Extraction, design and production, packaging and distribution, use and maintenance, reuse and recycling, and incineration and disposal (Danish EPA)
- R&D, investment, operation (US Army, Fisher 1971)
- Resource extraction, …manufacturing, .. distribution/transportation, .. use and maintenance, disposal, recovery, .. ancillary materials, …capital. (ISO14040/14041)
- Introduction, growth, maturity, (saturation), decline (e.g. business economists)
- Pre-phase, market phase, post-phase (Fassbender-Wynands 2001)
- Research, development, introduction, maturity, decline, abandonment (US Fish and wildlife)

These examples can be grouped based on their point of view. The first four are from the engineering type of angle as dominant in LCA. The use stage, of a certain duration, forms the centre with all production processes upstream and all processing after discarding downstream. The other three are related to market maturity, where the life time a product is not its individual technical life time but refers to the time the product may be on the market, with stages related to its market development. The CRT-screen for PCs, for example, came up with the PC, expanded in the still expanding PC market, but is now rapidly declining in market volume as it is being replaced by TFT-screens. It is expected to go out of production altogether within a few years, while the screens produced may technically last for decades. Most products, in their late market age, remain being produced in niche markets, like turbo-prop driven airplanes, being driven out of main markets by newer designs and products.

Five basic LCA-type of stages may generally be discerned, which can be further refined if needed:

1) Research, development and design
2) Primary production
3) Manufacturing
4) Use and maintenance
5) Disposal management

It may be noted that specific processes can belong to different stages at the same time, especially when recycling loops are involved. For example, the primary production of steel and aluminium also functions as disposal management as it involves the recycling of disposed-of products. Therefore, ISO indicates but does not define specific stages, as also is the case with Guinée et al (2003).

As with the life cycle, costs may be defined in many ways as well. Economists have defined costs as proceeds foregone, business as the outlays for products and production factors acquired, consumers and governments reckon with budget outlays, while welfare theorists have utility functions in mind. It is mostly free for everybody to choose his own most adequate way of cost specification. However, legislation may also influence the definition of costs. For example, starting in the Fifties of the last century, the US Army and Navy have developed detailed and obligatory standards for assessing costs of programmes. The Australian army has similar binding rules on life cycle costing[3]. Also in the US, all longer lasting (>2 years) publicly owned installations require life cycle based costing within general rules as laid down in national accounting standards[4], while major public programmes require a life cycle based Cost Benefit Analysis (CBA) with environmental externalities (see the *glossary*) quantified[5]. Guidelines on costing methods with a less binding nature exist with many agencies in many countries[6], and also with larger firms and accountants, and are subject of a broad literature in business administration.

With these variations, it will be clear that there is not just one LCC; many approaches and variants exist. Consequently, also many definitions of LCC can be found. One quite general definition has been chosen by the SETAC-Europe Working Group on LCC, and will be used here as a starting point: *"LCC is an assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor) with complimentary inclusion of externalities that are anticipated to be internalised in the decision-relevant future"* (Rebitzer 2003). This definition seems slightly too restrictive, as cost of externalities not expected to be internalised are excluded. We generalise the definition slightly so as to include all costs indirectly borne by others in society, now or in future. Also, only in special circumstances will all cost be covered; generally a relevant selection will be made for the decision at hand and for the stakeholder involved. To avoid the impression that only private entities can bear costs, public bodies may be mentioned explicitly. The generalised more encompassing definition resulting is:

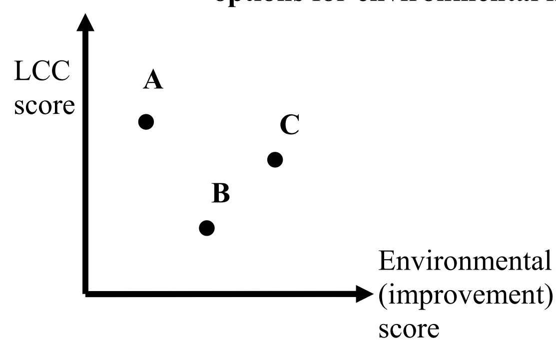
> *Life Cycle Cost are the cost induced by a product (good or service) in its life cycle as borne directly and indirectly by public and private actors involved, and possibly including cost of external effects as resulting for current and future generations through environmental mechanisms.*
> *Life Cycle Costing is a method to establish Life Cycle Cost.*

External effects of a non-environmental nature, eg those related to social aspects of sustainability, are not included in LCC, not even in the most encompassing LCC concepts. So 'social cost' is a separate issue for discussion.
An overview of definitions is in Annex 2.

1.2. Why use LCC?

The purpose of knowing and predicting costs of decisions and actions is quite self-evident in most situations: spending can only be done once and we would like to make the best of the means used. LCC has come up in the US six decades ago as a means to clarify cost not in relation to the purchase of a product or programme, but in relation to its intended functioning, during a certain period, thus involving the life cycle concept. In the last decades, a new reason for a fresh look at life cycle costing has emerged, as in many situations the explicit tradeoff between environmental effects on the one hand and economic costs, and benefits, on the other is logically required for optimizing decisions and policies. Environmental policy increasingly is under pressure to reduce costs, both its public cost but also the cost for firms induced by environmental policy. This pressure is increasing with internationalisation, as foreign competitors will receive an undue competitive advantage if home producers are bearing higher environmental costs. More generally, the discussion on sustainability actively relates economic and social aspects to environmental ones. For sustainable decision making, evaluations and choices will always require a comparison between economic and environmental aspects, either of past performance or of expected consequences of decisions. Internally consistent and mutually compatible methods are necessary to make such combined economic and environmental comparisons. The information on cost and environmental effect form the basis for a choice between different options for environmental improvement. Option A clearly is inferior to the other ones, being worse in both respects. The choice between B and C is less self-evident. One way to help decision making then is to compute the ratio of both scores, as an eco-efficiency or environmental effectiveness score.

Figure 1 **Life Cycle Cost and environmental score for options for environmental improvement**



LCC, especially the LCC resulting from Cost Benefit Analysis may also be used to quantify environmental effects in money terms, and is therefore seen as a most useful concept for linking environmental life cycle approaches to management decisions. Aggregating the economic and environmental score into one overall score is possible and usual in CBA, but not necessary. The advantage of having a single score in welfare terms has to be weighed against the high uncertainty on the evaluation of environmental effects, if really known. For example: effects of climate changing emissions, through climate change and further effect mechanisms, are highly uncertain empirically, while their long time horizon leads to as yet unresolved problems in evaluation, especially as related to discounting.[7] It may then be more acceptable to leave the environmental score separate, even if in monetary terms, to be compared to other costs. There is no information lost in using this eco-efficiency step, while information on the trade-off between economy and environment is added. CBA then would be back to its start by one of the founding fathers, Tinbergen (see Tinbergen 1961), who specified the non-market related effects in their own terms. In budget LCC, the inclusion of monetized environmental effects is not seem a logical step. If there are budget constraints, these hold for budget cost, not for social cost nor for monetized environmental effects.

A more subtle argument for LCC is that environmental considerations are often viewed as obstacles to business development, particularly in the short term (Hunkeler 2003b). This may be true but then would have to be established empirically. This requires a sound method, allowing for comparisons between environmental policies and measures as applied in different business situations. Outcomes of such analyses might be revealing, and allow for eco-efficient choices. The strategic argument for LCC, from an environmental point of view is that having such a method, technological development can be guided in a more rational direction, optimising the tradeoff environment-economy. This means that LCC combined with similarly standardised environmental analysis, as LCA, can help ease the pain of environmental cost also in the long run, by helping reduce them.

What will this paper contribute? The aim is twofold. The first aim is to clarify the field, by giving a broad overview of approaches and options for LCC, in a general framework. The second aim is to indicate how specific options for LCC may best be combined or even integrated with environmental effect analysis, aligning ecological and economic analysis.

In actual studies, a sequence of activities is involved, here formulated in a way to make the process of LCC studies compatible with the ISO steps for LCA (ISO 14040). Ultimately, the environmental analysis, LCA or other type would have to start at the same Goal and Scope definition and would result in one Interpretation, involving environmental and economic aspects, and other aspects of sustainability. The main phases of a study then are:

1. ***Goal & Scope definition***, for cost aspects including a specification of cost categories, the set-up of cost modelling and ways of cost aggregation;
2. ***Inventory analysis***, including system modelling, data collection and cost profile development;
3. ***Impact analysis***, including the aggregation of different costs and relating the cost analysis to the analysis of environmental effects;
4. ***Interpretation***, including the evaluation of alternatives as to their contribution to sustainability.

This paper will focus on the more general items which have to be specified in the goal and scope definition of an applied study.

2. Types and dimensions of LCC

2.1. Types of LCC

Four main types of LCC can be distinguished, based on their historical background. These four types of LCC are the Cost Benefit Analysis LCC (CBA-LCC), Budget LCC, LCC in a LCA context (LCA-LCC), and LCC as in Managerial Cost Accounting. This last variant will later be subsumed under Budget-LCC, see below, so there are three main types remaining: CBA-LCC, Budget LCC and LCA-LCC.

CBA (Cost Benefit Analysis[8])

CBA is the applied branch of welfare theory[9]. Being well embedded in economic theory, its practitioners are economists. CBA has been developed especially for major public investment plans, where markets often are lacking. The first Cost-Benefit Analyses were set up in relation to large public works like the Tennessee Valley reconstruction in the US in the Forties and the Delta plan for total see dyke renovation in the Netherlands after the flood disaster of 1953 (see Tinbergen 1961). Though the basic line of CBA as gathering pros and cons still exist, as with Tinbergen on the dyking program, the economic methods as have developed increasingly quantify intangibles in monetary terms, integrating the outcomes of a cost-benefit analysis in one or a few figures. Of course, the part of social cost and benefits not reflected in markets is not a driver in such markets. The focus on welfare effects of public policies and investments has been well developed, integrating this branch of applied economics into main stream welfare theory. Mishan, Dasgupta and Pearce are well known names in this field, with numerous publications by them and many more by others[10].

In several countries, especially the US, there is an extensive legal system in which cost and benefits of public regulations of a certain importance are to be assessed before and also after their introduction (see Sunstein 2002, pp19-22). These regulations focus on a balanced view between cost and benefits, seen in general terms as advantages and disadvantages. Though precursors exist, a big start of such types of analysis is seen with President Reagan's Executive Order of 1980, prescribing a cost and benefit analysis for major decisions, also environmental ones or ones with environmental consequences. The rules have been further developed under Clinton, in his Executive Order of 1993. In the Netherlands, public guidelines for cost-benefit analysis have been developed by the COBA (Commission on Cost-Benefit Analysis). Recently the CPB (Central Planning Bureau, established new guidelines, in principle for the evaluation options for road infrastructure but more broadly applicable, see note 6.

CBA customarily looks for costs, and benefits, over the life time of the project or program investigated. So this is a first main entry in the field of Life Cycle Costing, taking a social cost perspective. This seems quite appropriate when evaluating the combined economic and environmental consequences of choices.

Budget LCC

The second line to LCC originates from the public sphere as well, with the RAND Corporation coining the term Life Cycle Cost as early as the Fifties, and firstly applying it to the cost analysis of purchases of military equipment. The purchase price of the good there constitutes a small part of total cost only, as public development cost, cost of additional infrastructure, maintenance, servicing, and end-of-life cost all may be substantial. This line of concept development is continuing with substantial educational efforts going on in engineering sciences and with yearly a large number of applications, still with a focus on the US Department of Defence. However, the function based approach to budget costs is easily transferred to private sector applications, including investment decisions and covering specific subjects like product development. The basic approach to this private line in life cycle costing also is a systems analytical one, with environmental aspects now coming up in a number of applications. A good practical textbook is by Dhillon (Dhillon 1989).

Both CBA and budget LCC have a function oriented systems orientation, implying a life cycle approach. The central difference between CBA-type LCC and budget LCC is in terms of the types of cost mainly focussed on: social cost in CBA and budget cost in the typical budget LCC application.

Managerial accounting
A further group of cost analysis methods comes from the area of managerial accounting. Firms typically want to know what they will earn and what outlays are implied in producing their products. A good insight in the nature of cost drivers is essential for optimizing firms in terms of economic performance. Several accounting systems and broader: modelling systems exist, related to the goals of the firm, and the sophistication of the economic department. Handbooks have developed in great detail, showing how methods choices influence outcomes and their meaning. Many equivalents and variants are available, see a random selection of recent textbooks[11]. Interestingly, when trying to specify the fixed, variable and total cost of a product, allocation problems very similar to those in LCA come up both in managerial accounting and "traditional" life cycle costing, (as in Dhillon 1989) and have been recognised and solved there long before the still very vague solutions to the allocation problem in the ISO standards on LCA came up. When surveying the field of managerial accounting, the few contact points with steady state type of modelling in LCA are interesting but limited. Mostly, the methods used coincide with those in budget LCC, adding a lot of practical knowledge on the operational management of firms, which is not our prime concern here. So, analytically speaking, managerial cost accounting can be subsumed under budget LCC, and will not be treated independently further.

LCA-type LCC
The third line leading to life cycle cost analysis comes from environmental life cycle analysis. LCA having developed into a broadly applied tool for environmental analysis now needs a method for economic analysis that is matching. The LCA approach to the functional unit and the system definition involved are based on steady state type of analysis. Such analysis may be applied in cost analysis as is sometimes used in managerial cost accounting. When the focus is on cost allocation of multi-functional systems, a steady state type of approach with economic allocation is seen there as well (see Huppes 1993[12] and for a recent precision of this method in LCC Guinée 2004[13]). Matching to steady state type LCA would be a cost approach which is based on steady state costs. Current LCA models do not give a foundation for adding such cost aspects. Only indirectly may such an analysis be developed. Using the steady state engineering type of model, first the product related flows of purchases and sales would be expressed in monetary terms, as cost and proceeds of each activity. However, these would not be the cost and benefits of the system. The difference between purchases and sales, the value added, would be he measure for cost at the system level, as it is the use of factures of production, especially capital and labour, which ultimately constitutes cost. In input-output analysis and related systems for national accounting, such analysis is well established. Though structurally similar in LCA, the LCA cost analysis has not yet developed this way. In current LCA practice, costing approaches deviate from the steady state modelling of LCA. In most cost accounting for management support on strategies and investments, projects are defined in terms of a time series of costs and proceeds, with an aggregation into Net Present Value (or other methods, see below) involving a discounting of future costs, and possibly benefits. This is not compatible with common procedures in LCA. The link of LCA-LCC to both Cost Benefit Analysis and "traditional" budget LCC, both variants of economic systems analysis, has also been weak, due to fundamental differences in the modelling set-up and domains of system definition. To compound the difficulties in this complex area, LCA practitioners have borrowed the existing terminology from the budget-LCC group, without bothering much about the LCC methods that had been developed there.

The basic situation is that there is no standard method which combines the life cycle costing in a way that corresponds to the environmental part of the systems analysis of LCA. Different costing methods are used by LCA practitioners which mostly come from a business surroundings, where time series of costs (and benefits/proceeds) form the basis for costing while the LCA system model is a steady state model.

Specific methods

Within the budget-LCC approach, several methods have been developed with differing domains of application and with differences in modelling set-up, all following the same principle of life cycle view on a product function and its related investments and other costs. A short description is in the first table. How close they are can be seen in their names, with Total Cost of Ownership used in business and a very similar method named Total Ownership Cost being used by the US Navy. All methods have the intention to improve performance of the organisation or group they are applied for. Some have taken this goal as a defining characteristic, which seems not very practical terminology.

Table 1: Specific methods for Budget LCC

TOC Total Ownership Cost	TOC has been developed by the US navy. According to the US navy TOC “includes all costs associated with the research, development, procurement, operation, logistical support and disposal of an individual weapon system including the total supporting infrastructure that plans, manages and executes that weapon system program over its full life."
TCO Total Cost of Ownership	TCO has the same goals as TOC has, but originates from business. TCO is used extensively today. TCO is used to calculate the total costs (both direct and indirect) throughout the life cycle of a product or service, up till the preparation of the location of facilities for a next economic use.
ABB Activity Based Budgeting	Activity-based Budgeting means presenting a budget in terms of the cost of an organization's products and services, rather than the traditional budget that describes cost factors such as compensation, travel, and training[14].
ABC Activity Based Costing	ABC is a concept around which it can construct an economic model of its business that will provide the accurate and relevant cost information necessary to support sound business decisions of all types (Hicks 1999)[15]
FCA Full Cost Accounting	A tool to identify, quantify and allocate the direct and indirect environmental costs of ongoing company operations. Full cost accounting helps identify and qualify the following four types of costs for a product, process or project: direct costs, hidden costs, contingent liability costs, and less tangible costs. [16]
TCA Total Cost Accounting	Total Cost Accounting describes the long-term, comprehensive analysis of the full range of internal costs and savings resulting from pollution prevention projects and other environmental projects undertaken by a firm. TCA also stands for: Traditional Cost Accounting, True Cost Accounting, and Total Cost Assessment.
VCA Value Chain Analysis	Value Chain Analysis describes the activities that take place in a business and relates them to an analysis of the competitive strength of the business
CEA Cost Effectiveness Analysis	CEA starts from a pre-defined goal (e.g. reduce greenhouse gas emissions, increase packaging recycling) and identifies those technical and policy options which achieve the goal at lowest cost
SCC Supply Chain Costing	Relates to interfirm costing techniques[17]

Eco-efficiency	The WBCSD defines eco-efficiency as being achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity.[18]

2.2. Dimensions of LCC

The many approaches and variants of LCC make it difficult to understand and perform an LCC, especially for starters. To help clarify the differences between the variants, and to choose the best methods for analysis, LCC will be explained by means of four questions. These are:

- Which costs categories will be included?
- Whose costs will be included?
- How are the effects quantified?
- How are the results aggregated?

Each question relates to one of the four basic dimensions of LCC. Table 2 relates these dimensions with the questions. In the next two chapters, the four dimensions will be specified and explained. For clarification, a fictive example will be used, on a high capacity optical fibre door-to-door data transmission system. In the fifth chapter, a number of families of LCC will be discussed, with recommended combinations of the four dimensions. The data transmissions example will be presented in more detail there, in chapter 5.2.

Table 2: Overview of LCC dimensions

Dimensions	Questions	Examples	Chapter
Cost categories	Which cost will be included?	budget cost, personnel cost	3.1
Cost bearers	Whose cost will be included?	producer, society	3.2
Cost models	How are the effects quantified?	steady state, quasi-dynamic	4.1
Cost aggregation	How are the results aggregated?	average yearly cost, NPV	4.2

3. Cost categories and cost bearers

3.2. Cost categories

Four levels of cost categories will be distinguished: economic cost categories, life cycle stages, activity types, and cost elements. When making a LCC analysis, these four levels best be decided on sequentially.

Table 3: Overview of cost categories

1st level : in economics	Budget cost Market cost Alternative cost Social cost		
2nd level: life cycle stages	R&D Primary production Manufacturing Use Disposal management		
3rd level: activity types	development extraction purchase sales reuse management design agriculture manufacturing public relations recycling administration research testing packaging transport maintenance waste processing infrastructure		
4th level: exemplary elements	personnel equipment loans (rent) overheads materials disposal communication investments food production service electricity office cost building costs warranties infrastructure depreciation	direct taxes indirect taxes excises levies subsidies	damage prevention wastewater treatment exhaust gas reduction rehabilitation costs

The first level of cost categories reflect the inclusiveness of the cost analysis, from private to more social welfare oriented. The most simple and restricted type of cost is the budget cost, as of a single person or organization. The budget costs are the costs that directly come out-of-the-pocket; whatever it's legal or tax status. Budget costs only hold for very simple situations; even investments cost are not considered in this cost category, because the cost of borrowing and depreciation are rarely paid out of the pocket. Market costs are more theoretically embedded and still simple, including depreciations and all direct taxes and subsidies. A more complex version of the market cost, alternative costs, take into account price distortions of non- perfect markets. Also, when calculating alternative costs, for groups or society as a whole, transfer payments between individuals and organisations are left out of account. Transfer payments are payments not paid in return for a good or a service delivered, like taxes, subsidies, or gifts. Finally, social costs go one step further, in also reckoning with externalities. These externalities, or external effects (social and/or environmental), are by definition not reflected in market prices.

The second level concerns the different stages in the life cycle. The introduction showed that, depending on the angle, a life cycle can be subdivided into different sets of stages. Five stages are distinguished in this report:

1) **Research, development and design**: including laboratory work, design departments, experiments, prototypes, installation development
2) **Primary production**: including extraction of biotic and abiotic resources, agricultural production, packaging of intermediate products, and all waste processing from this phase/stage
3) **Manufacturing**: including materials processing, components manufacturing, packaging of intermediate products, transport, wholesale, retail, wastes processing
4) **Use**: including inputs for use and maintenance activities for good or service

5) **Disposal management**: including dismounting, grinding, sorting, transport, recycling, final wastes processing and storage.

For LCC analysis, all the life cycle stages are included in the analysis, in principle. All of them may include overheads of all kinds, within firms eg related to R&D, marketing and management, and with governments involving the built and education and research infrastructure.

In the third level, an overview of activity types is given. For every life cycle stage you have chosen, the relevant activity types may be selected as are relevant for a life cycle stage. Please note that this list is not a classification and hence is necessarily incomplete; only some frequently used activity types are listed. Finally, in the fourth level the most specific cost elements are distinguished. Displayed in the table are only some example cost elements, for its numbers are extensive. The chosen cost elements fully depend on the case, on conventions, and on the level of detail aspired. For instance, the purchase of a pencil can be grouped under writing products, office products, ancillary products, or even under materials. For your LCC study, please choose the relevant elements for all activity types. Please note that the elements in the last two element columns may not always be selected. Elements concerning taxes and subsidies should not be included when an alternative cost (or: collective cost) approach is chosen, while environmental elements, as monetized environmental damages, only belong to a social cost approach. Adding them to eg budget cost is not sensible.

To help, the cost activities and elements can be chosen based on product activity classifications as have been developed by the UN, with the most advanced system currently being the US NAICS[19] (North America Industry Classification System, formerly SIC) or, specifically for environment related activities, the European CEPA[20] (Classification of Environmental Protection Activities and Expenditure).

All cost elements ultimately derive from the cost of production factors only. In the days of Marx, two production factors were recognized: capital and labour. Nature is commonly added as a third production factor, by Marx already, but only in exceptional cases has it a price attached to it, based on collective ownership. In current more technology oriented models like the Cobb-Douglas (CES-type) production function[21] there is no limit on the number of production factors, eg adding energy, and resources to capital and labour.

3.2. Cost bearers

The second dimension concerns the cost bearers. The type of choice here directly relates to the system boundary chosen. For instance, when studying the costs of a product, one may decide to look at the costs of the producer only, or at the total costs of that product for the entire world, e.g. adding the cost borne by waste managers financed through taxes.

The choice for a cost bearer determines what costs are to be included in the LCC analysis. For this, a distinction will be made between downstream costs and upstream costs. These downstream and upstream costs are related to the life cycle of the product or service: upstream means earlier in the life cycle, whereas downstream means later in the life cycle, relative to some reference activity. For instance, upstream from a convenience store are producers, wile downstream users and waste processing companies can be found. Eight types of cost bearers may be distinguished as shown in table 4.

Table 4: Overview of cost bearers and cost covered

Cost bearer	upstream	downstream
Producer	almost all	none
Supply chain	all	none
Owner	almost all	almost all
User	almost all	almost all
Group	almost all	almost all
Life cycle	all	all
Country's society	all	all
Global society	all	all

The costs of a *producer* are basically the costs of producing a product or service. Costs from producers upstream are counted as long as they are reflected in the price of the purchased goods. This is, for example, not always the case for environmental costs and may not always be clear in the case of combined production (several products being produced together) when cost allocation rules as applied my differ. Related to the producer is the *supply chain*, which can include all actors from the extraction to the retail. For a supply chain all costs upstream will be taken into account.

Two other related cost bearers are *owners* and *users*. An owner may also be a user, while a user may not be the owner. All upstream costs that are processed in the price of the product or service (either rent or purchase) will be included. Furthermore, downstream costs may or may not be included.

Groups may be combinations of persons and organisations relevant in a certain situation. In the data transmission example, a group may consist of the users plus the service provider. Groups, as a flexible category, may overlap with any of the other categories. A specific group concerns all actors involved in the *life cycle* stages of a product of service, from extraction and production to use and disposal; that is the life cycle of the product, where all downstream and upstream costs are analyzed, including cost like infrastructure overheads, public waste management, etc.

The last two groups of cost bearers are a *country's society* and *global society*. The country's society excludes the costs abroad, and is not used often. One example of such an approach is the German 'Produktlinienanalyse'. The view of the global society is the most relevant one from a sustainability point of view, for most environmental effects don't stop at the border.

Applying these distinctions to an example, see table 5 shows how extreme differences in cost may result depending on the group the cost are related to. Basic data on this hypothetical case are in Section 5.2. below. Negative figures mean that there is a net proceed, for the data service provider because of payments by users exceed their costs, and for government due to Vale Added Tax on use fees exceeding the subsidies on the glass fibre cable system.

Table 5: Cost allotted to cost bearers in production and exploitation of a high capacity data transmission system

Net cost in current prices for:							
Producer	Users	Service provider	Users + Service provider	Users+ Service provider + Investors	Govern-ment	Society, no envir. cost	Society, including envir. cost
2500	**8800**	**-147**	**8653**	**4553**	**-458**	**4095**	**5125**

4. Cost models and cost aggregation

4.1. Cost models

The third dimension of LCC determines the type of model used to quantify costs. Preferably, this is the same model that is also used for the analysis of environmental and social aspects. In this section the various types of models will be explained by means of three characteristics: time, place and complexity. Time is a most basic factor, determining other options. For example, in steady state models no technology development can take place and factors determining this development are irrelevant for the model

Time
Eight types of models can be distinguished based on how these models handle time.

- Steady state models
- Comparative static equilibrium models
- Static optimisation models
- Quasi-dynamic models
- Dynamic optimisation models
- Dynamic models
- System dynamics models

Steady state models are conceptually the most simple ones, for they lack a time specification and assume all technologies to remain constant in time. Most LCA applications are steady state models, as are SFA (Substance Flow Analysis) and IOA models. *Comparative static equilibrium models* are extensively used in market analysis. These models are used to calculate equilibrium satiations for different starting conditions.

Static optimisation models calculate which set of characteristics results in an optimum situation. They can be used for situations where the time horizon is limited, or where the role of a certain mechanism is explored. *Dynamic optimisation models* indicate a path in time on how to maximise a goal function, like in terms of long term profits and turnover.

Quasi-dynamic models are time series which are exogenously determined. They are a compromise between steady-state and dynamic models. These models assume that most of the variables remain constant in time, but allow one or more of them to vary. Most TOC, LCC, CBA, and some IOA models are quasi-dynamic (IOA models may be steady state, quasi-dynamic or dynamic) .

Dynamic models explain the development of variables, with past values determining future ones. For example, economic models may predict investments in a following year based on the profits of this year. In contrast to quasi-dynamic models, the values are derived endogenously. Macro-economic models mostly are dynamic models. *System dynamics models* are a subclass of dynamic models, focusing on basic variables for long term development. A well known environmental example is the model used by the Club of Rome (Meadows 1972).[22]

These examples show that for LCAs generally steady state models are used, while for budget LCC studies generally quasi-dynamic models are used. This makes it difficult to directly compare the results of environmental models like LCA and economic models like budget LCC. For aligning these different approaches there are two options: either transform the LCA analysis into a quasi-dynamic model, or transform the LCC analysis into a steady state model. Such options will be discussed in more detail in the chapter 5.

Place
Models refer to a geographical unit, ranging from local to global. Most LCC models, as most LCAs, take a global view. Increasingly, however, the analysis is regionalised, specifying effects in specific regions. In LCA, this determines technology and modulates on environmental mechanisms. In LCC, there clearly also are large differences between regions in terms of cost of the same outputs. Though quite straightforward in terms of modelling, the empirical and presentational complexities in distinguishing regions are large and mostly unresolved in available tools. We will leave the regional differentiation option out of account on such practical grounds. However, in specifying technologies, the region of course is highly relevant.

Mechanism
When predicting the effects of choices, models can try to reflect full reality, becoming extremely complex, as complicated as reality itself, by incorporating all relevant causal mechanisms. Or they can be made simple, focussing on one a few relations and "keeping all other things constant", that is applying the *ceteris paribus* assumption.
In this sense, thus simplified models make conditional predictions, not full predictions. Although more complex models may better reflect and predict reality, simple models may give more insight, by showing pure mechanisms. Most models in the three lines of LCC are simple, avoiding larger numbers of mechanisms. However, in the Cost-Benefit Analysis type of LCC, quite complex models may be applied, including dynamic macro-economic models as a background for specific choices investigated. For example, when investing in environmental technologies in the downward part of the business cycle, the production factors used would have been idle. Hence, their use does not imply cost as cost are products foregone, in an economic sense. Though used and true in some sense, such variable mechanisms may well make systematic cost considerations impossible, as cost then would depend on timing and on adjoining macro-economic policy. For many decisions in an economic context, market mechanisms will play a central role in the effects resulting. Economists have developed partial equilibrium models, which by their limited scope cannot cover a full systems analysis as is required for LCA and LCC. Applied general equilibrium models cover the full system. However, in order to remain manageable the amount of detail has to be reduced to a level which makes both cost analysis and environmental analysis less useful. In practice, steady state models and quasi-dynamic models are used in combined economic and environmental analysis.

System boundaries
Ultimately, any economic activity is related to virtually all other activities through combinations of upstream and downstream links, through supply and demand in numerous markets. As the mechanisms are reduced to manageable proportions, also the system is reduced to manageable proportions, focussing on main processes involved and either cutting off less relevant processes, or estimating them as in hybrid LCA approaches. Allocation procedures play a further role in reducing the amount of processes involved in a study.

4.2. Cost aggregation

The last dimension of LCC concerns the way the different costs, and possibly benefits, are aggregated. When evaluating a large series of cost data, and especially when comparing them to environmental and social effects, an overall measure on cost is not just handy, but required. This overall measure may be some sum total, like the Net Present Value, or some yearly flow, like an average cost (per functional unit) per year. Cost models will usually differ with environmental modelling as in LCA in terms of the system boundaries effectively taken into account.

In addition to differences in form, cost aggregation methods also differ in the way they treat discounting, inflation, and chance and uncertainty. Some aggregation methods like the pay-back time don't allow discounting and inflation, and can only be used in simple methods. Others will allow defining a discounting rate.

Eight different ways to aggregate costs will be discussed here, with for each one a basic formula given. When discounting is involved, future costs (and benefits) count less then current ones. A simple rule can give some feel of touch. A future cost is worth half today depending on the discount rate, with the simple formula *halftime year = 70 / discount rate*. That is the *rule of seventy*. A 10% discount rate halves future costs and benefits every seven years. A cost amount of €1000 over twenty one years then has a present value of only €125. Please note that the last four methods can only be applied if the benefits and costs are specified independently.

Net Present Value (NPV)
The present value of cash inflow is subtracted from the present value of cash outflows. NPV compares the value of a dollar today versus the value of that same dollar in the future. The NPV refers to project as a whole or to the (not discounted) functional unit analysed. The formula for the computation of the NPV is:

$$NPV = \sum_{t=0}^{t=n} \frac{C_t}{(1+r)^t} \qquad (1)$$

In this formula is 'n' the number of years of analysis, 'r' the discount rate, and 'C_t' the estimated costs in year t. Using a term specific for cost might be considered, as the Present Value of Cost (eg as "PVC"). However, the general and widely used term NPV will hardly cause confusion, so we use that one only.

Steady State Costs (SSC) and Average yearly cost (AYC)
The average yearly cost is the sum of the yearly costs of a project or product, divided by it's functional running time. The steady state costs basically is the average yearly cost where the number of functional years (fn) is infinite (∞). As after an initial period all costs recur regularly, the steady state costs are equal to the average yearly costs. No discounting is involved. The equation for both is:

$$SSC = AYC = \frac{\sum_{t=1}^{t=n} C_t}{fn} \qquad (2)$$

In this formula is 'C_t' the cost in year t, 'n' the number of years of analysis, and 'fn' the number of functional years. In the data transmission example, the number of years in which costs are incurred (n), is 52, while the functional number of years of the system (fn) is 44. Given the number of units of function per year, the outcome can easily be transformed into SSC per unit of function.

Life time annuity
The annuity is characterized by a regularly paid constant amount (e.g. per year) over a limited period of time. The sum of the Net Present Value of all payments equals the total net present value as derived from the actual figures which usually will fluctuate in time. Many mortgages are life-time annuities. The life time-annuity is computed with the formula:

$$A = NPV * \frac{r}{1-(1+r)^{-fn}} \qquad (3)$$

In this formula is ‘r’ the discount rate, ‘fn’ the functional lifetime of the product or service, and ‘NPV’ the Net Present Value of the costs (explained above).

Eternal annuity
The eternal annuity is an annuity where the number of years (n) is infinite (∞). The eternal annuity can be computed with the same formula as the life time annuity:

$$A = NPV * \frac{r}{1-(1+r)^{-\infty}} = NPV * r \quad (4)$$

In this formula, ‘r’ is the discount rate, and ‘NPV’ is the Net Present Value of the costs. As for large fn the denominator converges to 1, the simplified second term of the formula results.

The following aggregate measures are based on the separate calculation of costs and benefits.

Internal rate of return (IRR)
The internal rate of return is defined as that discount rate which makes the present value of benefits equal to the present value of costs; i.e. the discount rate at which NPV is 0. The IRR can be computed by making the NPV formula equal to zero.

Profit
Profit seems a very straightforward term, although it can easily be made very complicated. The simplest equation of profit is:

$$P_t = B_t - C_t \quad \text{or} \quad \text{Profit = Benefits – Costs} \quad (5)$$

The problems arrive when defining the benefits and costs, which can be done in many ways. An example is where benefits equals sales and cost are purchases at other firms, where P_t resulting is gross Value Added. By subtracting depreciation net Value Added results. By further subtracting labour cost, returns to capital result, as a more capital oriented definition of profit. By next subtracting cost of loans a more restricted profit definition results. Profits are often defined in a legal context, with details not relevant for environmental systems analysis.

Pay-back time
A measure of the time required to return the initial investment. The preferred option has the shortest pay-back time. The pay-back time is easy to calculate, but does not include discounting or inflation. The pay-back time (N_{pb}) can be computed with the formula:

$$N_{pb} = \frac{C_0}{B} \quad (6)$$

In this formula, ‘C_0’ is the initial investment and ‘B’ is the yearly net benefits. This simple formula suggests a constant yearly net return. When this is not the case, the formula requires a summation term for the benefits.

Benefit-cost ratio (BCR)
Benefit-cost ratio is the ration of the present value of future benefits at the specified discount rate, to the present value of the future costs discounted at the same rate. It requires a clear distinction between cost and negative benefits, which both in theory and in actual practice may be difficult to specify. Therefore

application of BCR in a comparative context is not advisable. The BCR is computed using the following formula:

$$BCR = \frac{\sum_{t=0}^{t=n} B_t \big/ (1+r)^t}{\sum_{t=0}^{t=n} C_t \big/ (1+r)^t} \quad (7)$$

In this formula, ‘B_t’ is the Benefits in year t, ‘C_t’ is the Costs in year t and ‘r’ is the discount rate.

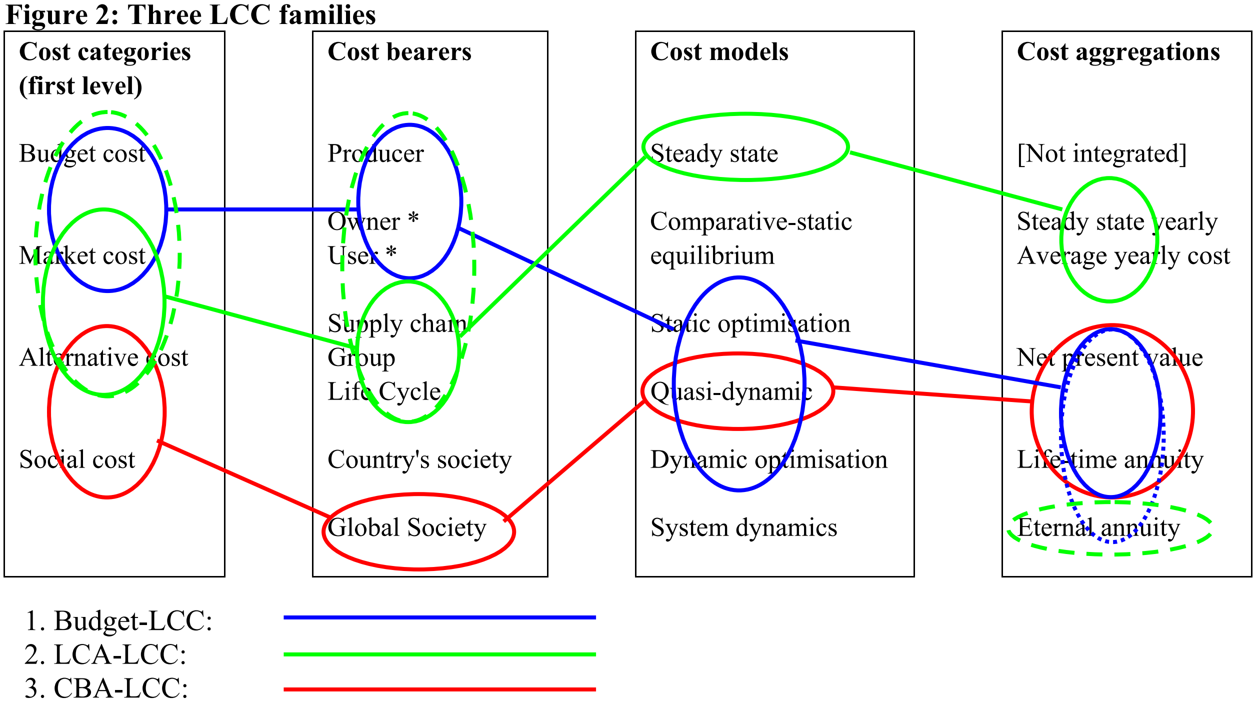
Inflation and discount rate
In specifying the aggregate cost, the basis is formed by a time series. Discounting in budget LCC typically will use a market based discount rate. However, in this rate, a premium for inflation is incorporated in some way, while the prices in the time series will usually be based on current price levels. There is quite some CBA literature on the subject of how to deal with inflation. Somehow, an adjusted discount rate is to be constructed, e.g. as the actual market rate minus the inflation rate.

5. LCC families and an exemplary case application

5.1. LCC families

With these four dimensions many combinations are possible. Luckily, these dimensions are not fully independent. For instance, when using a steady state model, it is not so sensible to use a number of aggregations, like the Net Present Value. Other combinations are possible, but are unnecessary complicate or not very sensible. Expressing the costs of a single producer using a social cost approach is one example. In line with their historical development three groups of more or less similar approaches can be distinguished, as LCC families. The three families are budget-LCC, as developed for budget analysis for government purchases and generalised to business applications; CBA-LCC, as developed for public investment projects, and generalised to broader sets of investment programmes; and LCA-LCC, newly emerging and currently establishing its precise methodology. Within each family several options exist. In terms of the several dimensions all families all are at least partly overlapping, easily creating confusion on which method actually is used, as numerical outcomes very much depend on the method applied. Especially when a comparison between projects where the analysis has been done with different methods, the outcome may depend more on the method used than on the underlying reality of the case. Application of LCC in eco-efficiency analysis is still very much hampered by this state of affairs. The next figure shows three families with their main variants. Developments in LCA-LCC might lead to new options, like an eternal annuity as method for cost aggregation, see the green dotted right down in figure 2.

Figure 2: Three LCC families



* owner and user: including government and public bodies

5.2. A hypothetical example: a high capacity glass cable network for data transmission

The application of the three families, with variants in the dimensions, will be demonstrated with a hypothetical example: the costs of a door-to-door high capacity glass cable network. The goal and scope of the study may be the choice for this cable system or, e.g., a lower capacity system combined with copper-wiring and ADSL type of data transmission, or high frequency radio transmission systems. Each option has its specific time profile. This example refers to one option only the high capacity glass cable network. This example has been chosen, because it can be used to demonstrate the differences between the various options in LCC. The costs of the cable system are shown in table 6. Beware: they are hypothetical, also the environmental cost as indicated in monetary terms.

Table 6: The costs of a high capacity glass cable network. Operation of the system included, operation of connected user/consumer hardware not (yet) included

All money values are in MEuro per year in the indicated period.

Years	**A.** Construction, maintenance & operation	**B**. Payment to investors	**C**. User fees	**D**. Government subsidy/ VAT	**E.** Environ mental damage
1 to 5 (building)	500	-350	0	150	150
6 to 30 (operational)	25	130	200	-32	5
31 (closed for maintenance)	200	130	0	0	20
32 to 50 (operational)	30	130	200	-32	5
51 to 52 (demolition)	100	0	0	100	20
Totals, no discounting	**4095**	**4100**	**8800**	**-458**	**1030**
general data					
inflation in %, constant for all years		3			
capital rent		7			
social time preference		3			
value added tax in %		20			
functional years:		44			

The table distinguishes five cost categories: construction, maintenance, and operation; payments to investors; user fees; government subsidies and VAT; and environmental damage. These categories do not relate to one specific level of cost categories (table 3); actually, only the construction, maintenance & operation costs (and in the social cost view, also the environmental costs) are real costs as involving the use of scarce alternatively applicable resources. All other costs here are transfer payments between different cost bearers.

The costs are calculated for five time periods; these are: a five year building period, two operational periods (respectively 25 and 19 years), one year in which the system is closed for major overhaul (not so realistic but to add possible complexity to the computation), and two years of demolition. The table displays the costs per year in the indicated period; negative numbers indicate that for the entity bearing cost there are net proceeds. A government subsidizing a high capacity data transmission system, eg, may well have tax proceeds from its exploitation being higher than this subsidy. Please note that of the fifty two years where cost accrue, the system is functioning for forty four years only.

Data on the inflation, capital rent, and social time preference are needed to compute the discount rate for market, alternative, and social approaches. The VAT rate is needed to calculate the VAT on the user fee.

Table 6 can be used to calculate the costs (or negative costs, which are revenues) of the system for various persons or groups. Table 7 shows the net costs for some cost bearers and groups of cost bearers.

Table 7: Overview of net costs for some (groups of) cost bearers, no discounting.

Years	Producer	Users	Service Provider	Users + Service provider	Users+ Service provider + Investors	Government:	Society, no environmental costs	Society, including environmental costs
	Part A	**C**	**A+B-C-D**	**A+B-D**	**A-D**	**D**	**A**	**A+E**
1-5	2500	0	0	0	1750	750	2500	3250
6-30	0	5000	-325	4675	1425	-800	625	750
31	0	0	330	330	200	0	200	220
32-50	0	3800	-152	3648	1178	-608	570	665
51-52	0	0	0	0	0	200	200	240
totals	**2500**	**8800**	**-147**	**8653**	**4553**	**-458**	**4095**	**5125**

The letters in the table show which of the cost categories from table 6 are used to compute the costs. Please note that this is one of the many possible tables that can be made based on the definition of net costs.

The *producer* is only responsible for the construction of the hardware, especially cables; which will cost M€2500 (five times M€500). The *users* of the system will pay an annual fee of M€200. They only have to pay when the system is operational; that is for 44 years (44 times M€200 = M€8000). There won't be much discussion on the net costs of these two cost bearers: they are the most simple ones because they don't receive any money.

The calculation of the net cost of the *service provider* is more disputable. The costs of the service provider consist of the building, maintenance and operation costs, the payments to the investors, and of taxes to the government (VAT). The user fees are his benefits (negative costs). Here, it can be discussed if the VAT payments and user fee benefits should be included in the net costs. The same holds for the groups of cost bearers containing the service provider: the users and service provider; the users, service provider and investors. When looking at the *users and service provider* together, fee payments can be left out of account as in-group transfer payments. What remains are building and maintenance costs, payments to the investors, and VAT payments. If this tax payment is a relevant money flow is a matter of taste, as it may well be assumed that alternative activities would generate taxes as well. It surely makes public investment projects look nicer. When including the investors and looking at the *users, service provider, and investors*, also the payments to/from the investors are left out of account. What then remains are only the maintenance and operation costs, and the VAT payments (again, disputable).

The *Government* pays a part of the building costs (the rest is paid by the investors through the Service Provider) and all demolition costs, and receives VAT on the fee payments. Again, the inclusion of the tax payments can be discussed.

When looking at *society* all transfer payment cancel out and are to be neglected. When excluding the environmental costs, only the construction, maintenance and demolition costs are used. Naturally, the environmental costs are included when looking also looking at the social costs.
The costs will be calculated for a number of members of the three LCC families (figure 2). The models will not be discussed in detail, because the data in this example is to simplistic to model them. Figure 2 can be used as a reference to choose the proper model. Table 8 will show the results for different cost categories, cost bearers and cost aggregations.

Table 8: Overview of costs for a number of combinations

Costing family	Aggregation method	Producer	User	Society w/o envir.	w. envir.	Discount rate
Budget-LCC	AYC (=SSC)	56	200	93	-	none
	NPV	2 050	1 915	2 320	-	7%
	NPV/yr service	47	44	53	-	7%
	lifetime annuity	151	141	171	-	7%
	eternal annuity	143	134	162	-	7%
CBA-LCC	NPV	2 289	4 150	2 932	3 739	3%
	life time annuity	94	171	120	154	3%
LCA-LCC	SSC (=AYC)	56	-	93	116	none
	eternal annuity	143	-	162	209	7%
	eternal annuity	68	-	87	112	3%

To calculate the NPV the data as given in time are discounted, while in a possible next step annuities may be computed, using the same discount rates in principle. In this example, the data is discounted to year 0, the year in which the costs of the system are studied. The discount rate is based on the cost category, and on the values of the inflation rate, capital rent, and the social time preference (table 6).When using the budget-LCC family with a market cost approach, the inflation rate and capital rent can be used to get the discount rate. In this case, the discounting rate is 10-3=7%. When using the CBA-LCC, the discount rate reflects social time preference and uncertainties, in this case put at 3%. Many governments require higher discount rates when establishing the attractiveness of investments. Using lower discount rates makes investments look more attractive. In all situations where prices are specified in current price levels, the discount rate is to be taken net of the inflation rate.

The last table (9) shows, as an example, the nominal and discounted costs of the producer, which already diverge substantially in the relatively short period of five years.

Table 9: Nominal (= 0%) and discounted costs for the system builder

year	Discounting 0%	3%	7%
1	500	485	467
2	500	471	436
3	500	457	408
4	500	444	381
5	500	431	356
total	***2 500***	***2 289***	***2 050***

6. Discussion and conclusions

6.1. Discussion

The main approaches to Life Cycle Costing as have developed historically in the last five decades differ in a number of basic characteristics or dimensions. However, there is not a one-to-one correspondence between characteristics and approaches, as within approaches different choices may be defensible depending on the case at hand. For example, though life cycle approaches in principle take a cradle-to-grave view, a cradle-to-gate view sometimes may be quite relevant. Also, budget cost of one organisation may be of overriding importance in a decision, while at the same time alternative and social costs may be relevant from a more overarching point of view. Whatever the characteristics may be of specific applications and the procedures involved in them, the analytical support by LCC clearly has to cover quite different situations. For practical or theoretical reasons different approaches may well be valuable, either single or in combinations. However, specific choices may be dangerous in the sense of not being well defined or definable. In passing the main characteristics as grouped in the dimensions of the framework, such dangers will be indicated.

Cost categories
The discussions on cost categories can be structured into levels (see table 3). The top level concerns the fundamental point of view to be taken into account in the analysis. Choice of level is a matter of the point of view to be reflected, simple or more complex private considerations, as in budget and market cost, or a more full view on society as a whole, in term of simple measures building on market cost or more sophisticated views related to market imperfections, as alternative cost, or lacking market, going to social cost incorporating environmental effects within the same welfare-theoretical framework. The second and third level deal with completeness, whatever the choice at level 1. Should R&D be incorporated in life cycle cost? How to deal with other overheads as for the built an the cultural infrastructure? More sophisticated and more complete together make life cycle costing more expensive itself. The fourth level is a help in finding relevant cost items. One element is how to deal with taxes and subsidies, a question not relevant for budget cost but highly relevant for alternative and social cost, where such transfer payments should not be included.

Cost bearers
In many decisions, different stakeholders represent different organisations and different collectivities. A single organisation like a firm or a household surely will want to have a view on their cost, as their budget cost. However, for long-term decisions it may be wise for firms to reckon also with collective or social cost. Subsidies hardly will last forever, and negative effects may well be reflected in corrective policies, in due time. So, in addition to their private views, also private organisations will want to know cost at a more collective level, and of a more abstract type.
What comes up in the example on data transmission costs is that in between the full collectivity of all involved in the life cycle, and the single firm bearing cost, the partial groupings are extremely difficult to define in a non-arbitrary way. See table 5 where cost jojo between different partial groupings. Adding public bodies to the service provider brings up the question if taxes received are negative cost or proceeds not to be combined with costs. It seems impossible to resolve this problem on the basis of actual payment. Only activity based costing, may solve this problem to some extent, by showing the gross value added as costs of the activity. However, dealing with such an analysis at the process level requires much more information than usually is available at the life cycle system where costs are to be established.

Cost models
Combining a system definition with cost types and cost bearers to some extent determines the model to be used. Going for alternative costs requires a modelling of markets in their deviation from fully competitive markets. In principle the more sophisticated choices made at level one of cost categories, the more complex models are required for quantification. For more frequent decisions the time and manpower of a study will be limited, as will therefore be their sophistication and completeness. Real dynamic modelling, which may most resemble real life developments, is by far the most costly type of analysis. Only stylised models may be made operational, and hardly ever have been linked to a detailed environmental analysis. Some macro-level energy models touch upon the dynamics for decision support. In actual practice of decision making on specific technologies and products, and the environmental policies related to them, the available modelling types are reduced to two: quasi-dynamic models where development in time is based on considerations exogenous to the model, or steady state models where a technological view on operations with constant ratios between inputs and outputs is assumed for all processes involved. The quasi-dynamic model forms the backbone for budget LCC and CBA, while steady state models form the core of LCA type LCCs. Cost-benefit types of LCC will tend to be more sophisticated in their market analysis, with possible satellite models indicating most relevant developments. Mostly, however, they are of the quasi-dynamic type. Transforming a quasi-dynamic model into steady state model is a relatively straightforward affair, by repeating the time series till all activities take place in all following years in constant amounts. Transforming a steady state model into a quasi-dynamic one requires additional information. Also, conventions as to involving closed loops in a system require a conceptual re-orientation before the transformation can be made.

Cost aggregation
Whatever the exact cost categories is used, the aggregation options are largely determined by the modelling set-up. Budget-LCC and CBA-LCC have a series of costs specified in time and have to aggregate this set of figures into a total. The LCA type of analysis gives average costs in terms of the system, for a unit of function, which may be chosen to reflect the amount of function in one year. As most costs are given on a yearly basis this seems to be a sensible rule for quantifying the functional unit. For all time specified costs, a number of aggregation methods are applicable, somehow expressing future cost in terms of cost in a base year, for convenience chosen as year zero, the year the decision is supposed to take place, see formula 1. The net present value of costs is to be related to the function delivered. Also for the benefits of having the function, the discounting should in principle be applied, as the units of function delivered are often spread out in time as well. Just adding up the number of functional units over the system lifetime is not compatible with on the other hand discounting cost. This problem has not been resolved in budget LCC where defining 'the function' is a problem very similar to that in LCA. In CBA, the function itself is specified in time and then monetised, allowing for a consistent full discounting procedure. In LCA type of cost modelling, all costs occur in each year, in the amount needed for the amount of function taken as a reference. Taking this amount as a yearly amount quite easily produces the total cost per year for the amount of function per year, as Steady State Costs, being the same as Average Yearly Costs. No discounting is involved. How may these very different cost types be related?
A simple trick may make the outcomes comparable to some extent. First, the project series implied in steady state ("having the cable system forever") is to be transformed into a Net Present Value. Doing so requires information on the time structure of costs. Even if eternity is taken for the time horizon in the steady state analysis, the time profile of the first number of "consecutive" projects may have quit some influence on the NPV. Next, as with budget LCC, this Net Present Value (of having the function forever) can be transformed into an eternal annuity, using the same discount rate as being used for computing the present value. This eternal annuity differs from the eternal annuity which can be constructed for budget LCC and CBA-LCC. There the basis is the net present value for having the 44 years of function, so by dividing by 44 one can compute the NP and annuity per unit of function. For the steady state, the annuity is the amount needed for having the function forever; therefore this annuity is larger. Also, it cannot be expresses per unit of function, as the function is everlasting and one then would divide by infinity.

Concluding, several transformations are possible, but the fundamental difference can only be bridged by choosing for one or the other modelling approach.

Main families

Surveying the main options in the four dimensions of our framework, three main families may be discerned. The budget LCC joins two historically independent developments, one focused at budget cost of governments, the LCC as developed by RAND in the US, the other, as management cost accounting, focused at budget cost for the firm. In their set-up they can be the same, while in operational practice choices as e.g. on relevant discount rates may differ a bit. The CBA-LCC is different from them in the central focus on social welfare, using the more abstract cost categories of level 1. Both are different from LCA-LCC, with the engineering steady state type of model at its core. Only in the aggregation step may these different approaches to life cycle costing be reconciled, transforming the net present value into an eternal annuity that is equivalent to steady state costs.

6.2. Conclusions

1. Legitimate options exist which may lead to at least sixteen different computation methods for life cycle costs, each with a different outcome. At least three types of cost aggregation method may be combined with most of these sixteen computational methods, which do not add information but diversify the outcomes.
2. Practical choices within methods, as on base year, market discount rate, and expected lifetime of components, may lead to diverging outcomes within one method. These practical choices often have the nature of simplifying assumptions and should be made explicitly.
3. Extending the available data to cover different methods seems an obvious solution to increase comparability between studies.
4. When making comparisons between studies, both the methods applied and the main practical choices should be specified.
5. A standardised format for the specification of methods, and hence a specification of these methods, is highly desirable for application of LCC in a comparison between cases based on different studies, as often is the case in eco-efficiency analysis. The framework provide in this study may be seen as a proposal for starting standardisation.
6. The procedural standards for LCA as specified in ISO14040 may, with slight adaptations, be used for LCC as well. This allows for well-aligned studies covering the environmental and the economic part of sustainability analysis.
7. Specifying and discounting long term environmental effects is not possible in a well founded way; discounting itself will easily be at variance with well accepted (but a bit fuzzy) intergenerational ethical principles.
8. Fundamental differences in treatment of time in modelling techniques divide methods two groups: those based on time specification and discounting, as with the quasi-dynamic and dynamic modelling as with budget LCC and CBA-LCC, and those based on steady state modelling or more general comparative static equilibrium modelling, as in LCA-LCC.
9. In the modelling stage, quasi-dynamic models can easily be transformed into steady state models, but not the other way around.
10. In the interpretation stage, outcomes of (quasi)dynamic models can be aggregated first into the Net Present Value, and then next into an equivalent eternal annuity. This eternal annuity is directly comparable to average cost of steady state modelling.

Notes and Reference

[1] UNEP report Life Cycle Approaches, in press.
[2] ComEd. 1996. Maximizing Assets, Minimizing Environmental Impacts Through Life Cycle Management. Promotional documentation.
[3] Anon. (1998) Life-cycle Costing in the Department of Defence, Department of Defence, Australian National Audit Office, Canberra, ISSN 1036-7632; ISBN 0 644 38849 8
4 FASAB (1996, 2001) Federal Accounting Standards Advisory Board Standard Number 6, as Amended (2001) requires the use of total life cycle cost for all equipment lasting long2r than 2 years.
5 This development was introduced by president Nixon, extended by Ford, and came to full maturity under president Clinton, in Executive Order 12866. 58 Fed. Reg. 51735 (1993). However, some major environmental laws, like the Clean Air Act of 1970, expressly forbid cost-benefit considerations in developing policies, see CR Sunstein (2002) *Risk and reason. Safety, law and the environment.* Cambridge University Press, Cambridge, 232-233.
6 In the Netherlands there has been a standing government committee for advice on this subject, and recently a guideline has been published for the ministries of Economic Affairs and Waterworks and Public Infrastructure: CJJ Eijgenraam, CC. Koopmans, PJG Tang, ACP Verster. 2000. Evaluatie van infrastructuurprojecten. Leidraad voor kosten-batenanalyse. (Evaluation of infrastructural projects. Guidelines for cost-benefit analysis. The Hague: Centraal Planbureau and Nederlands Economisch Instituut.
7 See a survey of the issues in Portney and Weyant 1999 (PR Portney & JP Weyant, Eds, 1999, *Discounting and intergenerational equity*, Resources for the Future, Washington
[8] CBA is sometimes called benefit-cost analysis. The Google score is 385 000 hits on "cost benefit analysis" 30 000 on "benefit cost analysis", that is 12 : 1. We stick to the winner.
9 Dietz, W. Hafkamp, J. van der Straten (red.), Basisboek Milieu-economie, Boom, Amsterdam, 1994 (in Dutch)
J. van den Bergh (Ed), Handbook of Environmental and Resource Economics, Cheltenham: Edward Elgar, 1999; D W Bromley (Ed) The Handbook of Environmental Economics, Blackwell, Oxford 1995; Tom Tietenberg, Environmental and Natural Resource Economics, 5th edition, Addison Wesley Longman, Inc. 2000
10 For example: Dasgupta 1972, Mishan 1972 & Mishan 1975.
11 A random selection of recent textbooks involving cost accounting:

- Garrison, R.H. and E. W. Noreen. 2003. *Managerial Accounting, 10th edition.* Irwin: McGraw-Hill.
- Warren, C.S. and J.M. Reeve. 2004. *Financial Accounting for Future Business Leaders*. Thomson,
- Jimbalvo, J. 2003. Managerial Accounting. John Wiley & Sons.
- Kumen, J. and M. Werner. 2003. *Introduction to Management Accounting*. Pearson, 2nd Edition.
- Atkinson, A.A., R.S. Kaplan and S.M. Young. 2003. *Management Accounting, fourth edition.* New Jersey, Prentice Hall.
- Horngren, C. T., S.M. Datar and G. Foster. 2003. *Cost Accounting: A Managerial Emphasis.* New Jersey: Prentice-Hall.

[12] Huppes, G. 1993. Macro-environmental policy: principles and design. With cases on milk packaging, cadmium, phosphorus and nitrogen, and energy and global warming. Amsterdam: Elsevier Science Publishers
[13] Guinée JB, Heijungs R, Huppes G. 2004. Economic Allocation: Examples and Derived Decision Tree. *Int. J. LCA* 9 (1), 23-33
[14] Reference: www.NMDA.com/abb
[15] Hicks, D.T. 1999. *Activity Based Costing*: *Making it Work for Small and Mid-Sized Companies,* second edition. New York, John Wiley & Sons.
[16] From web site of the European Environment Agency. GEMI. 1994. Quoted by: International Institute for Industrial Development Economics at Lund University. 2000. Continuity, credibility and comparability. Sweden.
[17] LaLonde, Bernard J. and Terrance L. Pohlen, "Issues in Supply Chain Costing," *International Journal of Logistics Management*, Vol 7, No 1, 1996, pp. 1-12
[18] World Business Council for Sustainable Development: www.wbcsd.org
[19] For more information on NAICS: www.census.gov/epcd/www/naics.html.
[20] For more information on CEPA: http://unstats.un.org/unsd/cr/family2.asp?Cl=232.
[21] See: Tietenberg, T.H. 1996. *Environmental and Natural Resource Economics.* NewYork: HarperCollins, p513.
[22] Meadows, D.H., D.L. Meadows, J. Randers and W.W. Behrens III. 1972. *The Limits to Growth.* New York: Universe Books.

Annexes

Annex 1 Glossary

Discounting Discounting converts future costs and revenues occuring at different times to equivalent costs at a common point in time.

Environmental cost There are two basic definitions:

1: Environmental damage expressed in monetary terms, as in CBA

2: The cost of measures to prevent environmental damage.

Life cycle 1 All processes or activities involved in procuring a unit of function of a product, taking into account the life time of the product involved.

Life cycle 2 The time period a product is on the market, including its development stage.

External effect; externality Effect of an economic activity on the welfare of individuals which is not reflected in the prices in the markets related to this activity.

External cost Two non-compatible meanings:

1. Cost of external effects
2. Cost not borne by an organisation, as a corollary of internal costs.

Internal cost Cost borne by an organisation in supplying or consuming a product.

Taxes, indirect Taxes not related to products or activities, as on income, on profit or capital.

Taxes, direct Taxes on products or economic activities, like value added tax or turnover tax. A broad definition includes duties and excises.

Transfer payments Transfer payments are payments between governments and private persons or organisations, involving taxes and subsidies. Payments for public services, like waste management may be included as well under this heading.

Annex 2 Examples of LCC definitions[1]

Definition of Life cycle costs and life cycle costing

- The producer's product life cycle costs "refers to all the costs a producer incurs over the life of a single product including costs for product conception, design, product and process development, production, logistics, marketing, service and guarantees". [Artto 1994, 29].
- Life Cycle Costs are the total costs from the inception to disposal for both equipment and projects [Barringer 1996].
- Means extending horizons beyond the purchase costs of products to consider all the costs that will be incurred over their operating lifetime – including, in principle, the environmental costs involved in buying, using and disposing of the product [Bennett and James 1998, 48].
- Life Cycle Cost refers to all costs associated with the system or product and applied to the defined life cycle. Life cycle cost includes (but is not necessary limited to) the following:
  - Research and development cost,
  - Production and construction cost,
  - Operation and support cost,
  - Retirement and disposal cost.

  Life Cycle Cost is basically determined by identifying functions in each phase of the life cycle; costing those functions; applying the appropriate costs by function on a year-to-year schedule; and ultimately accumulating the cost includes all direct producer and costumer costs [Blanchard 1978].
- Life Cycle Cost: the sum of all costs incurred during the life time of an item, i.e., the total of procurement and ownership costs [Dhillon 1988, p. 3].
- LCC is a method of calculating the total cost of a physical asset throughout its life. Life-cycle costing is concerned with all costs of ownership, and takes account of the costs incurred by an asset from its acquisition to its disposal, including design, installation, operating, and maintenance costs [the economist].
- Life Cycle Cost, according to the U.S. Office of Management and budget, means the sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred, or estimated to be incurred, in the design, development, production, operation, maintenance, and support of a major system over its anticipated useful life span. More recently, life-cycle cost has been defined in an Executive Order as the amortised annual cost of a product, including capital costs, installation costs, operating costs, maintenance costs, and disposal costs discounted over the life time of a product. The term may also be used more expansively to include societal costs [EPA 1995, p. 33].
- Life Cycle Cost (LCC) is the sum of all money flows, which are caused by the existence of a specific product. It is calculated by aggregation of costs and revenues related to the processes making up the product's life cycle [grEEEn 2002a, p. 45].

[1] Based on a list for the SETAC WG on LCC by Karli James and Kerstin Lichtenvort, with extensions.

- Life Cycle Costing (LCC) in its pure sense is an assessment of all the costs which are caused by the existence of a specific product. This includes all costs paid for and revenues received by all the parties which take part in the products life cycle. However, LCC is usually performed by one of these parties in order to calculate the economic consequences of investment decisions for its own sake. Therefore LCC is often performed from the viewpoint of one of the parties [Veefkind 1998]. In these cases there is an overlapping with the concept of "Total Costs of Ownership" which provides the total costs of owning a product. [grEEEn 2002b, p. 14].
- LCC generally has a "cradle to grave" approach. The life cycle actually commences with the initial identification of a consumer need and extends through system planning, research, design and development, production, consumer use, system logistics support in the field, and ultimate system retirement and material disposal [Blanchard 1978], in [grEEEn 2002b, p. 15].
- The life-cycle of technical products or systems can be defined as the time span between the begin of product development and final disposal. Usually this time span is divided in following life cycle phases:
  - Research and development
  - Manufacturing
  - Use
  - End of life

  The costs incurred by all parties involved and aggregated over the whole life cycle are designated as Life Cycle Costs. [Hallmann, Ley 1999, p. 740 f].
- Life Cycle Costing: An economic assessment of an item, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars [Kirk 1995, p. 254].
- Considers the full costs over the product's (system's, operation's) life cycle - from research through disposal, from cradle to grave [Kreuze and Newell 1997, 62].
- LCC has been used to help project managers and engineers choose the most cost effective approach from a series of alternatives - allowing them to "buy right rather than buy cheap". Life Cycle Costs are those based upon design, development, production, operation, maintenance and disposal. LCC emphasises the best business practice by enhancing economic competitiveness to work for the lowest long term cost of ownership. [McManus 2003].
- There is an Australian standard on LCC (AS4536) which defines the Life Cycle Cost as: "the total cost throughout its life including planning, design, acquisition and support costs and any other costs directly attributable to owning or using the asset".It proposes that there is life cost analysis and life cost planning. Life cost planning concerns the assessment and comparison of options and alternatives during the design/planning stages. Life cost analysis enables the creation, operation and disposal costs of a selected product to be monitored throughout its life to enable accurate and timely decision making as to how the costs can be minimised. This is used as the basis for monitoring and managing costs over an assets or products life. [McManus 2003].
- LCC is an assessment of all costs associated with the life cycle of a product that are directly covered by any or more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor)

with complimentary inclusion of externalities that are anticipated to be internalised in the decision-relevant future [Rebitzer & Hunkeler 2003].

- A method in which all costs are identified with a product (process or activity) throughout its lifetime, from raw material acquisition to disposal. Life cycle costing may focus on internal costs, or it may attempt to consider internal and external costs [Schaltegger and Burritt 2000, 112]
- The relationship between what a consumer pays for a product and the total cost the consumer incurs over the life cycle of using the product [Shank and Govindarajan 1993, 15].
- The process of assessing the cost of a product over its life cycle or portion thereof. The life cycle cost is the sum of acquisition cost and ownership cost of a product over its life cycle. [Standards Australia and Standards New Zealand 1999, 7].
- Life cycle costs refer to all the costs that the producer will incur over the product's life cycle, including design, manufacture, marketing, logistics and service. Whole life cost of a product includes life cycle costs as well as costs that consumers incur, such as the costs of installation, operation, maintenance, revitalization and disposal. [Shields and Young 1991, 39].
- A life cycle cost estimate encompasses all costs, including design, development, operation, maintenance and final disposition over the anticipate life span of a process, product, facility or system [US EPA 1998, 122].
- Life cycle cost is defined as all internal and external costs associated with a product, process, project or activity throughout its entire life cycle - from raw materials acquisition to recycling/final disposal of waste materials. Internal costs are those directly incurred by an organisation (e.g., capital, labor, energy and regulatory compliance costs). External costs are those not directly incurred by the organisation (e.g., resource depletion, water contamination, and human health effects)". [Weitz *et al.* 1994, 28].
- Life-cycle costs include all internal costs plus external costs incurred throughout the entire life cycle of a product, process, or activity [White *et al.* 1996, 7.11].

Total cost accounting

- Total cost accounting (TCA) methods provide a means of allocating specific costs to individual products. Researchers at Georgia Tech are applying TCA methods to poultry processing plant operations to identify the contribution of environmental costs to specific products' costs. They are also developing tools to help identify and control environmental costs. [Georgia Tech Research Institute 1996].
- TCA refers to methods which attempt to develop better accounting practices to credit the full cost of pollution. These methods include all costs including direct capital and operating costs, indirect or hidden costs (e.g., compliance costs, insurance, on-site waste management, operation of pollution control equipment), future liability (penalties and fines and payments due to personal injury and property damage), and less tangible benefits (e.g., revenue from enhanced company image). Some

costs are difficult if not impossible to quantify, such as improved company image or reduced liability [Raynet].

- A hybrid term sometimes used as a synonym for either of the definitions given to "full cost accounting," or "Total Cost Assessment". - Full Cost Accounting: A method of financial and management accounting that allocates all direct and indirect historical costs to a product or process. [EPA 1998].

Total cost of ownership

- TCO (total cost of ownership) is a type of calculation designed to help consumers and enterprise managers assess both direct and indirect costs and benefits related to the purchase of any IT component. The intention is to arrive at a final figure that will reflect the effective cost of purchase, all things considered. When you decide to buy a computer you may go through a TCO analysis: for example, the greater cost price of a high-end computer might be one consideration, but one that would have to be balanced by adding likely repair costs and earlier replacement to the cost of the bargain brand [KEMP's Technologies 2002].
- Total cost of ownership (TCO) is a model developed by Gartner Group to analyse the direct and indirect costs of owning and using hardware and software. Managers of enterprise systems use various versions of TCO to lower costs while increasing the benefits of information technology deployments [Emigh 1999].
- Ownership cost: the sum of all costs other than the procurement cost during the life time of a item [Dhillon 1988, p. 3].

Full-cost pricing (FCP)

- In full-cost pricing, prices reflect all harmful cost to society and the environment. (Miller 2004, p692)

- Annex 3 Life Cycle Costing - Literature Survey CML

This survey focuses on LCC and applications in relation to environmental analysis. The vast literature on CBA has been left out of account, except for a few basic readers.

Arnse, K. 1997. De industrie en het Milieu: Hogere Milieukosten, Maar Minder Druk op het Milieu [Industry and Environment: higher environmental Costs, but less Pressure on the Environment]. *Industriemonitor* 2:6-10.

Anderson, R.F. 1996. Total Cost of Ownership: Getting Past the 10% Solution. *Hydrocarbon Processing* 75(7):105-9.

Arrow, K.J. 1999. Discounting, Morality, and Gaming. In: *Discounting and Intergenerational Equity*, edited by P.R. Portney and J.P. Weyant, 13-21.Washington: Resources for the Future.

Artto, K.A. 1994. Life Cycle Cost Concepts and Methodologies. *Journal of Cost Management* 8(3): 28-32.

American Society for Testing and Materials (ASTM). 1999. *Practice E917-99: Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*. West Conshohocken, USA: ASTM.

Azar, C. and S.H. Schneider. 2003. Are the economic costs of (non)-stabilizing the atmosphere prohibitive? A response to Gerlag and Papyrakis. *Ecological Economics* 46(3):329-332.

Badgett, L., B. Hawke and K. Humphrey. 1995. *Analysis of Pollution Prevention Investments Using Total Cost Assessments: a Case Study in the Electronics Industry.* Seattle: Pacific Northwest Pollution Prevention Research Center.

Bage G.F. and R. Samon. 2003. The Econo-Environmental Return (EER) - A Link between Environmental Impacts and Economic Aspects in a Life Cycle Thinking Perspective. *International Journal of Life Cycle Assessment* 8(4):246-251

Baker, W.R. 1978. Basic Guidelines for Understanding Life-Cycle Costing. Plant Engineering 32(11): 171-176.

Bartlett E. and N. Howard 2000. Informing the Decision Makers on the Cost and Value of Green Building. *Building Research and Information* 28(5-6): 315-324.

Bartolomeo, M., Bennett, M., Bouma, J. J., Heydkamp, P., James, P., Wolters, T. (2000). Environmental management accounting in Europe: current practice and future potential. *The European Accounting Review* 9(1): 31-52.

Beaver, C. 2000. LCA and Total Cost Assessment. *Environmental Progress* 19(2): 130-139

Bebbington, J., R. Gray, C. Hibbitt and E. Kirk. 2001. *Full Cost Accounting: An Agenda For Action.* ACCA Research Report 73. London: ACCA

Behrens, M.L., B.I. Dvorak and W.E. Woldt. 2000. Implications of hidden costs: Comparison of Bitumen Testing Procedures. *Environmental Technology* 21(3): 243-255.

Bennett, M. and P. James (contrib. Ed.). 1998. *The Green Bottom Line: Environmental Accounting for Management, Current Practice and Future Trends.* Sheffield: Greenleaf Publishing.

Bennet, M. and P. James. 1998. Life-Cycle Costing and Packaging at Xerox Ltd. In: *The Green Bottom Line: Environmental Accounting for Management, Current Practice and Future Trends*, edited by M. Bennett and P. James, 347-361. Sheffield: Greenleaf Publishing.

Bennet, M. and P. James. 1998. The Green Bottom Line. In: *The Green Bottom Line: Environmental Accounting for Management, Current Practice and Future Trends,* edited by M. Bennett and P. James, 30-60. Sheffield: Greenleaf Publish

Berg, H.J. van den, J. Bulte and R. van der Wal. 1992. *Kostencalculatie Nader Bekeken: Activity Based Costing: een "Nieuwe" Ontwikkeling [A closer Look at the Calculation of Costs: Activity Based Costing: a "new" Development].* Report / Centre for Research in Business Economics ; 9205/ACC. Rotterdam: Erasmus University.

Bierman H. Jr., T.R. Dyckman and R.W. Hilton. 1990. *Cost Accounting: Concepts and Managerial Applications.* Boston: PWS-Kent.

Boonekamp, P.G.M. [et al.] 2000. *Milieukosten van genomen Besparingsmaatregelen [Environmental Costs of saving Measures].* ECN report: ECN-C--00-045. Petten: Energieonderzoek Centrum Nederland.

Borghols, E.G., J. J.M. van Dunné and A.J.A. Stevens. 1992. *Milieukosten en Fiscus [Environmental Costs and the Treasury].* Fed's actualiteiten ; nr. 17. Deventer: Fed Reeks.

Boussabaine, H. and R. Kirkham. 2003. *Whole Life-Cycle Costing: Risk and Risk Responses*. Malden, MA : Blackwell Publishing.

Bragg, S.M. 2001. *Cost Accounting: a Comprehensive Guide*. New York: Wiley.

Brimson, J.A. 1991. *Activity Accounting : An Activity-Based Costing Approach.* The Wiley/national association of accountants professional book series. New York, N.Y. [etc.]: Wiley.

Brown, R.J. and R.R. Yanuck. 1980. *Life Cycle Costing: a Practical Guide for Energy Managers.* Atlanta: Fairmont.

Brown, R.J. and R.R. Yanuck. 1985. *Introduction to Life Cycle Costing*. Atlanta, Ga : Fairmont Press [etc] ; Englewood Cliffs, N.J : Prentice-Hall.
Buffinton, D.E. and R.J. Black. 1981. Life-Cycle Costing of Plant Materials for Residential Energy-Conservation. *Proceedings of the Florida State Horticultural Society* 94: 205-208.
Camobreco, V., J. Sheehan, J. Duffield and M. Graboski. 2000. Understanding the Life-Cycle Costs and Environmental Profile of Biodiesel and Petroleum Diesel Fuel. In: The Society of Automotive Engineers (SAE), 1-8. Total Life Cycle Conference and Exposition, Detroit, Michigan.
Canadian Institute of Chartered Accountants. 1997. *Full Cost Accounting from an Environmental Perspective.* Toronto: Canadian Institute of Chartered Accountants.
Centraal Bureau voor de Statistiek.1979-. Milieukosten van bedrijven .. .[Environmental Costs of Companies]. Voorburg: CBS.
Cline, W.R. 1999. Discounting for the Very Long Term. In: *Discounting and Intergenerational Equity,* edited by P.R. Portney and J.P. Weyant, 131-140.Washington: Resources for the Future.
Coenenberg, A.G., T. Fisher, J. Schmitz. 1994. Target Costing und Product Life Cycle Costing als Instrumente des Kostenmanagements. *Zeitschrift fur Planung* 5(5): 1-38.
Cohan, D. 1996. Integrated Life Cycle Management. In *Design for Environment - Creating Eco-Efficient Products and Processes,* edited by J. Fiskel, 137-151. New York: McGraw-Hill.
Cole, R.J. and E. Sterner 2000. Reconciling Theory and Practice of Life-Cycle Costing. *Building Research and Information* 28(5-6): 368-375.
Cooper, R. and R.S. Kaplan. 1197. Activity Based Systems: Measuring the costs of Resource Usage. In: *Readings in Management Accounting,* edited by S.M. Young, 45-54. New Jersey: Prentice Hall.
Cooper, R. and R.S. Kaplan. 1998. The Promis - and Perils - of Integrated Cost Systems. *Harvard Business Review* July/ August: 109-119
Cooper, R. and R. Slagmulder. 1999. *Supply Chain Development for the Lean Enterprise - Interorganisational Cost Management.* Portland: Productivity Press.
Curran, M.A. 1996. *Environmental Life-Cycle Assessment*. New York: McGraw Hill.
Dasgupta, A.K. and D.W. Pearce. 1972. *Cost-benefit analysis: Theory and practice*. London: MacMillan.
Dasgupta, P., K.-G. Mäler and S. Barrett. 1999. Intergenerational Equity, Social Discount Rates, and Global Warming. In: *Discounting and Intergenerational Equity,* edited by P.R. Portney and J.P. Weyant, 51-77.Washington: Resources for the Future.
Dhillon, B.S. 1989. *Life Cycle Costing: Techniques, Models and Applications*. New York: Gordon and Breach, London: Taylor & Francis.
Directoraat-Generaal Milieubeheer. 1998. *Kosten en Baten in het Milieubeleid: Definities en Berekeningsmethoden: Herziene Uitgave van de Standaardmethode voor het Definiëren en berekenen van de Kosten van Milieubeheer [Costs and Benefits in Environmental Policy: Definitions and Calculation Methods: Revised Edition of the Standard Method for Defining and Calculation of the Costs of Environmental Management].* Publicatiereeks milieustrategie; 1998/6. Den Haag: Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Centrale Directie Voorlichting en Externe Betrekkingen.
Ditz, D., J. Ranganathan and R.D. Banks. 1998. Green Ledgers: An Overview. In: The Green Bottom Line: Environmental Accounting for Management, Current Practice and Future Trends, edited by M. Bennett and P. James, 164-187. Sheffield: Greenleaf Publishing.
Durairaj, S.K., S.K. Ong, A.Y.C. Nee and R.B.H. Tan. 2002. Evaluation of Life Cycle Cost Analysis Methodologies. *Corporate Environmental Strategy* 9(1): 30-39.
Edwards. S., E. Bartlet and I. Dickie. 2000. *Whole Life Costing and Life-Cycle Assessment for Sustainable Building Design.* Building Research Establishment digest. 452. [S.l.]: Building Research Establishment.
Ellram, L.M. 1993. A Framework for Total Cost of Ownership. *The International Journal of Logistics Management* 4(2): 49-60.
Ellram, L.M. 1993. A Taxonomy of Total Cost of Ownership Models. *Journal of Business Logistics* 15(1): 171-192.
Ellram, L.M. 1993. Total Cost of Ownership: Elements and Implementation. *International Journal of Purchasing and Materials Management* 29(4): 2-11.
Ellram, L.M. 1995. Activity-Based Costing and Total Cost of Ownership: a Critical Linkage. *Journal of Cost Management* 9(4): 22-30.
Elram, L.M. 1995. Total Cost of Ownership: An analysis approach for purchasing. *International Journal of Physical Distribution & Logistics Management* 25(8): 4-23.

Elram, L.M., E. Feitzinger. 1997. Using total profit analysis to model supply chain decisions. *Journal of Cost Management* 11(1): 12-22.

Elram, L.M., S.P. Siferd. 1998. Total Cost of Ownership: A key concept in strategic cost management decisions. *Journal of Business Logistics* 19(1): 55-84.

Emblemsvåg, J. and B. A. Bras. 1997. A Method for Life-Cycle Design Cost Assessments using Activity-Based Costing and Uncertainty. *International Journal of Design Automation* 3(4): 339-354.

Emblemsvåg, J. and B. A. Bras. 2001. *Activity-Based Cost and Environmental Management: a Different Approach to ISO 14000 Compliance*. Dordrecht: Kluwer Academic Publishers.

Emblemsvåg, J. 2003. *Life-Cycle Costing: Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks.* Hoboken, N.J: Wiley.

Enander, R.T. 1996. *Hazardous Waste Tracking and Cost Accounting Practice.* Boca Raton: CRC Press.

Engelen, R.F.J.M., P.F.L. Feimann and C.H. Oostenrijk. 1998. Provinciale Milieukosten: Model en Resultaten [Environmental Costs : Model and Results]. RIVM rapport 773008001. Bilthoven: Rijksinstituut voor Volksgezondheid en Milieu.

U.S. Environmnental Protection Agency (EPA). 1995. *Federal Facility Pollution Prevention Project Analysis: a Primer for Applying Life Cycle and Total Cost Assessment Concepts.* Washington: EPA.

Epstein, M.J. and M.-J. Roy. 1997. Integrating Environnmental Impacts into Capital Investment Decision. *Greener Management International* 17(spring):69-87

Epstein, M.J. and B. Birchard. 1999. *Counting what Counts, Turning Corporate Accountability to Competitive Advantage.* Reading Perseus Books.

Epstein, E.M. 2003. *Full Cost Accounting Protocol for Biosolids Management.* Alexandria, VA: Water Environment Research Foundation.

Fassbender-Wynands, E. 2001. *Umweltorientierte Lebenszyklusrechnung - Instrument zur Unterstützung de Umweltkostenmanagements [Environmental life cycle analysis. - A Tool to support environmental management*]. Wiesbaden: Gabler Verlag

Feiler, A.M. 1986. Incorporating Risk Analysis Into Life-Cycle Costing. *Proceedings Annual Reliability and Maintainability Symposium (SYM):* 469-476.

Ferry. D J O. and R. Flanagan. 1991. Life Cycle Costing - a Radical Approach. London: Construction Industry Research and Information Association.

Federal Facilities Council (FFC). 2001. Sustainable Federal Facilities: a Guide to Integrating Value Engineering, Life-Cycle Costing, and Sustainable Development. Washington, D.C.: National Academy Press, 2001.

Finch, E.F. 1994. The Uncertain Role of Life-Cycle Costing in the Renewable Energy Debate. *Renewable Energy* 5(5-8): 1436-1443.

Fisher, G.H. 1971. *Cost Considerations in Systems Analysis.* New York : American Elsevier.

Fisher, T.M. (ed.) 2000. *Kosten-Controlling- Neue Methoden und Inhalte.* Stuttgart: Schäffer-Poeschel Verlag.

Fiskel J. (ed.). 1996. *Design for Environment - Creating Eco-Efficient Products and Processes.* New York: McGraw-Hill.

Flanagan, R., G. Norman, J. Meadows and G. Robinson. 1989. Life Cycle Costing: Theory and Practice. Oxford [etc.]: BSP Professional Books.

Fröhling, O. and D. Spilker. 1990. Life Cycle Costing. *IO Management* 59(10):74-78.

Fuller, S. K. and S.R. Petersen. 1996. *Life-Cycle Costing Manual for the Federal Energy Management Program.* NIST Handbook 135. Washington: Government Printing Office.

Geitner, F. and D. Galster. 2000. Using Life-Cycle Costing Tools. *Chemical Engineering* 107(2): 80-86.

Grieco, P.L. and M. Pilachowski. 1995. *Activity Based Costing: the Key to Worldclass Performance*. West Palm Beach: PT Publication Inc.

Goldbach, M. 2002. Organisation Settings in Supply Chain Costing. In: *Cost Management in Supply Chains,* edited by S. Seuring and M. Goldbach, 89-108. Heidelberg: Physica Verlag.

Götze, U. 2000. Lebenzykluskosten. In: *Kosten-Controlling- Neue Methoden und Inhalte,* edited by T.M. Fisher, 265-289. Stuttgart: Schäffer-Poeschel Verlag.

Gray, R. & J. Bebbington (Eds.). 2001. *Accounting for the Environment.* 2nd ed. London [etc.]: Sage. 1st ed.: 1993.

Griffith, J.W. and B.J. Keely. 1979. Workbook Of Life-Cycle Costing. *CHEMTECH* 9(4): 242-246.

Heilig, G.C. 1995. Formulas For Life-Cycle Costing. *Chemical Processing* 58(8): 12.

Heiskanen, E. 2002. The institutional logic of life cycle thinking. *Journal of Cleaner Production* 10(5): 427-437.

Helberg, C., J.E. Galletly and J.R. Bicheno 1994. Simulating Activity-Based Costing. *Industrial Management & Data Systems* 94(9): 3-8.

Helllweg, S., T.B. Hofstetter and K. Hungerbuehle. 2003.Discounting and the Environment: Should Current Impacts be Weighted Differently then Impacts Harming Future Generations? *International Journal of Life Cycle Assessment* 8(1):8-18.

Huiberts, R.G.J. 1994. Milieukosten voor bedrijven: een overzicht van milieuheffingen, -tarieven, -rechten en leges [Environ-
mental Costs for Companies: an overview of Ecotaxes, Environmental Tariffs, Laws and Fees]. Den Haag: KPMG Milieu.

Hunkeler, D. 2000. Life Cycle Profit Optimisation. *International Journal of Life Cycle Assessment* 5(1): 59-62.

Hunkeler, D., K. Lichtenvort and G. Rebitzer. 2003. *Methodology and Application of Life Cycle Costing : Background and Initial Work Plan Proposal for SETAC Working Group.* [S.l.]: SETAC LCC Working Group.

Hunkeler, D. & G. Rebitzer 2003. Life Cycle Costing: Paving the Road in Sustainable Development? *International Journal of Life Cycle Assessment* 8(2): 109-110.

IEC 1996. *Evaluation du Cout du Cycle de Vie = Life Cycle Costing*. Series IEC standard; Dependability management; Application Guide. Geneve: IEC.

James, K.L. 2002. Making Environmental Costs more Visible and Relevant – How can It be done? Paper presented at Packaging Clean and Green 2002, Australian Institute of Packaging, Melbourne, Australia, March 21–22, 2002.

James, K.L. 2003. *Environmental Life Cycle Costing ìn the Australian Food Packaging Supply Chain.* Melbourne: Department of Accounting and Finance, Faculty of Business and Law, Victoria University. PhD Thesis.

James, K. 2003. Life Cycle Costing Definitions. Discussion Paper. Melbourne: SETAC LCC Working Group.

Jantzen, J. & P. van Duyse. 1994. Milieukosten en sociaal-economische effecten op provinciaal niveau [Environmental Costs and Social-Economic Effects at the Provincial Level]. 's-Gravenhage : Instituut voor Toegepaste Milieu-Economie.

Jantzen, J., H. Heijnes & P. van Duyse. 1995. Technische vooruitgang en milieukosten: aanzet tot methodiekontwikkeling [Technical Progress and Environmental Costs: an Initiative for Methodology Development]. 's-Gravenhage: Instituut voor Toegepaste Milieu-Economie (TME).

Janzen, H. 1997. Erscheinungsformen und Trends des Lebenzyklusdenkens aus der Perspektive umweltorientierter Unternehmensplanung. *Zeitschrift für angewandte Umwelforschnung* 10(3): 313-326.

Jorissen, W.C.L. 1993. Life Cycle Costing: Levensduurkosten en -opbrengsten van duurzame Produktiemiddelen [Life Cycle Costing: the LIfe Span Costs and Profits of Sustainable Production]. Afstudeerverslagen ; BDK2212, TU Eindhoven. Fac. Bedrijfskunde. Eindhoven:Technische Universiteit Eindhoven.

Kane, G., J.L. Stoyell, C.R. Howarth, P. Norman and R.Vaughan. 2000. A Stepwise Life Cycle Engineering Methodology for the Clean Design of Large Made to Order Products. *Journal of Engineering Design* 11(2): 175-189.

Kaplan, R.S. 1992. In defence of Activity-Based Cost Management. *Management Accounting* 70(10): 58-63.

Kaplan, R.S. and Cooper, R. 1997. *Cost & Effect - Using Integrated Cost Systems to Drive Profitability and Performance.* Boston: Harvard Business School Press.

Kennedy, M.L. 1998. *Total Cost Asessment for Environmental Engineers and Managers.* New York: Wiley.

Kennedy, M.L. 1998. Critical Issues of Total Cost Assessment: Gathering Environmental Cost Data for P2. *Pollution Prevention Review,* Spring 1998: 9

Keoleian, G. A., S. Blanchard and P. Reppe. 2001. Life Cycle Energy, Costs, and Strategies for Improving a Single Family House. *Journal of Industrial Ecology* 4(2): 135-156.

Kirschner E. 1994. Full-Cost Accounting for the Environment. *Chemical Week* 154(9): 25-26.

Klopffer, W. 2003. Life-Cycle Based Methods for Sustainable Product Development. *International Journal of Life Cycle Assessment* 8(3): 157-159.

Koch, D. 2002. Environmental Management - Dow Chemical Pilot of Total "Business" Cost Assessment Methodology: a Tool to Translate EHS. *Environmental Progress* 21(1): 20-28.

Kreuze, J. G. and G.E. Newell. 1994. ABC and Life-Cycle Costing for Environmental Expenditures. In *Readings in Management Accounting, edited by M. Young,* 62-67. New Yersey: Prentice Hall.

Kumaran, D., S., S.K. Ong, R.B.H. Tan and A.YC. Nee. 2001. Environmental Life Cycle Cost Analysis of Products. *Environmental Management and Health* 12(3): 260-276.

Lablonde, B.L. and T.L. Pohlen.1996. Issues in Supply Chain Costing. *The International Journal of Logistics Management* 7(1): 1-12.

Lam, J.C. & W.W. Chan. 2001. Life Cycle and Green Cost Analysis of Energy-Efficient Lighting for Hotels. *Architectural Science Review* 44(2): 135-138.

Lefebvre, C. and A. van den Brande. 1992. *Activity Based Costing : een Nieuw Boekhoudkundig ABC? [Activity Bases Costing: a new Accounting ABC?].* Bedrijfseconomische verhandeling / Departement voor Toegepaste Economische Wetenschappen ; nr. 9201. Leuven: Katholieke Universiteit Leuven.
Lichtenvort, K. 2003. *Summary of Definitions on LCC.* Discussion Paper. Melbourne: SETAC LCC Working Group.
Lin, B. , J. Collins and R.K. Su. 2001. Supply Chain Costing: An Activity-Based Perspective. *International Journal of Physical Distribution & Logistics Management* 31(10): 702-713.
Lippiatt, B.C and A.S. Boyles. 2001. Using BEES to Select Cost-Effective Green Products. *International Journal of Life Cycle Assessment* 6(2): 76-80.
Lippiatt, B.C. 2002. *BEES 3.0 -Bulding for Environmental and Economic Sustainability: Technical Manual and User Guide.* NISTIR report 6916. Gaithersburg: National institute of Standards and Technology.
Maas, K. and J. Jantzen. 1999. *Life Cycle Costing: a Survey of Methods to Account for Financial and External Life Cycle Costs in Water Management.* RIZA werk-document. 99.107X. The Hague: RIZA ; Institute for Applied Environmental Economics (TME
Marshall, H.E. and R. Ruegg. 1980. *Simplified Energy Design Economics.* NBS SP report 544. Washington: National Bureau of Standards.
Marshall, H.E. 1981. *Recommended Practice for Measuring Benefit/Cost and Savings-to-investment Ratios for buildings and Building systems.*NBSIR report81-2397. Washington: National Bureau of Standards.
Marshall, H.E., R.T. Ruegg and P. Driscoll. 1994. Life Cycle Costing. In: *Architectural Graphic Standards 9th edition,* edited by ?, 122-123. New York: hn Wiley & Sons.
Marshall, H.E. 1995. *Least-Cost Energy Decisions for Buildings - Part III: Choosing Economic Evaluation Methods.* NISTIR report 5604. Gaithersburg: National Istitute of Standards and Technology.
Miller, G.T. Living in the environment Principles, connections and solutions Brooks/Cole-Thomson, Pacific Grove
Mishan, E.J. 1972. *Elements of Cost-Benefit Analysis.* London: Allen and Urwin.
Mishan, E.J. 1975, sec. rev. ed. *Cost-benefit analysis.* London: Allen and Urwin.
Nagel, P.J.A. and B.S. Blanchard. 1987. A Probabilistic Approach to Life-Cycle Costing. *South African Statistical Journal* 21(2): 187-188.
Nager, M.H. 2001. Environmental Quality in the Supply Chain of an Original Equipment Manufacturer in the Electronics Industry: Research, Development, Evaluation, Validation and Implementation of Environmental Performance Tools in the Scope of Total Cost of Ownership. Delft: Technische Universiteit Delft. Thesis Technische Universiteit Delft.
Nakamura, S. and Y. Kondon. 2003. *On the Application of Input-Output Analysis to Life Cycle Costing.* Discussion Paper. Tokyo: SETAC LCC Working Group.
National Defense Center for Environmental Excellence (NDCEE). 1999. *Environmental Cost Analysis Methodology ECAM Handbook.* Fairfax, VA, USA: Concurrent Technologies Corporation.
Nieuwenhof, R. van den (red.) ; M. Bouman … [et al.]. 1994. *Milieukosten Voorkomen [Preventing Environmental Costs].* 's-Gravenhage : DELWEL
Nordhaus, W.D. 1999. Discounting and Public Policies That Affect the Distant Future. In: *Discounting and Intergenerational Equity*, edited by P.R. Portney and J.P. Weyant, 145-162.Washington: Resources for the Future.
O'Guin, M.C. 1991. *The Complete Guide to Activity-Based Costing.* London: Prentice Hall.
Partovi, F.Y. 1991. An Analytic Hierarchy Approach to Activity-Based Costing. *International Journal of Production Economics* 22(2): 151-161.
Pervushin, S.P. 1988. Full Cost Accounting: Organization and Methodological Foundations. *Problems of Economics* 30(9): 53-69.
Pfohl, H.-C. and K.L. Wübbenhorst. 1982. Lebenszykluskosten. *Journal für Betriebswirtschaft* 3:142-155.
Pontarollo, G. 2000. Environmental Life Cycle Cost Analysis: A Review of Economic, Energy and Green House Gas Emission Impacts of Asphalt and Concrete Pavements, Mémoire de maîtrise, Université de Toronto.
Portney, P.R. and J.P. Weyant (Eds.). 1999. *Discounting and Intergenerational Equity*. Washington: Resources for the Future.
Prentice-Hall editorial staff. 1965. *Encyclopedia of Cost Accounting Systems*. Englewood Cliffs, N.J.: Prentice-Hall.
Quarles, R. & and A. Stratton. 1998. A Case Study Using ABC to Quantify Environmental Costs in Plant Operations. *Journal of Cost Management* (september/october): 23-32.
Raffish, N. 1997. How much does that product really cost? Finding out may be as easy as ABC. In: *Readings in Management Accounting*, edited by M. Young, 36-39. New Jearsy: Prentice Hall.

Rebitzer, G. 2002. Integrating Life Cycle Costing and Life Cycle Assessment for Managing Costs and Environmental Impacts in Supply Chains. In: *Cost Management in Supply Chains,* edited by S. Seuring and M. Goldbach, 128-146. Heidelberg: Physica-Verlag.
Rebitzer, G. and S. Seuring. 2003. Methodology and Application of Life Cycle Costing. *International Journal of Life Cycle Assessment* 8(2): 110-111.
Riezler, S. 1996. *Lebenszykluskostenrechnung - Instrument des Controlling Strategischer Projecte.* Thesis: Wiesbaden: Gabler Verlag.
Roodvoets, D.L. 2003. Reducing Life-Cycle Costs. *College Planning and Management* 6(8): 8-10.
Ruegg, R.T., J.S. McConnaughey and T. Sav. 1978. *Life-Cycle Costing: a Guide for Selecting Energy Conservation Projects for Public Buildings.* NBS Building Science Series; 113. Washington, D.C : US Government Printing Office.
Ruegg, R.T. , S.R. Petersen and H.E. Marshall. 1980. *Recommended practice for Measuring Life Cycle Costs for Buildings and Building Systems.* NBSIR report 80-2040. Washington: National Bureau of Standards.
Ruegg, R.T. and H.E. Marshall. 1990. *Building Economics: Theory and Practice.*New York: Chapman and Hall.
Russell, D., A. Patel and G. Wilkinson-Riddle. 2002. *Cost Accounting: an Essential Guide.* London: Pearson Education.
Sarkis, J. (ed.) 2001. *Greener Manufacturing and Operations - From Design to Delivery and Back.* Sheffield: Greenleaf Publishing.
Sas, H.J.W. ; met medew. J.P. van Soest … [et al.]. 1994. *Verwijdering van Huishoudelijk Kunststofafval: Analyse van Milieu-Effecten en Kosten [Disposal of Household Plastics Waste: Analysis of Environmental Effects and Costs].* Delft: Centrum voor Energiebesparing en Schone Technologie. 2 parts.
Schaltegger, S. (ed.) 1996. *Life Cycle Assessment (LCA)- Quo vadis?* Basel: Birkhäuser Verlag.
Schaltegger, S. 1997. Economics of Life Cycle Assessment: Inefficiency of the Present Approach. *Business Strategy and the Environment* 6:1-8.
Schaltegger, S. and R. Burritt. 2000. *Contemporary Environmental Accounting: Issues, Concepts and Practice.* Sheffield: Greenleaf.
Schmidt, W.-P. 2003. Life Cycle Costing as Part of Design for Environment. *International Journal of Life Cycle Assessment* 8(3):167-174.
Schneider, S.H., K. Kuntz-Duriseti and C. Azar. 2000. Costing non-linearities, surprises and irreversible events. *Pacific and Asian Journal of Energy* 10: 81-106.
Sekhar, S.C. and K.L.C. Toon. 1998. On the Study of Energy Performance and Life Cycle Cost of Smart Window. *Energy and Buildings* 28(3): 307-316.
Sen, A. K. 1977. Rational fools: a critique of the behavioral assumptions of economic theory. *Philosophy and Public Affairs* 6: 317-344.
Seuring, S. 2001. A Framework for Green Supply Chain Costing - A Fashion Industry example. In: *Greener Manufacturing and Operations - From Design to Delivery and Back,* edited by J. Sarkis, 150-160. Sheffield: Greenleaf Publshing.
Seuring, S. 2001. *Supply Chain Costing - Kostenmanagement in der Wertschöpfungskette mit Target Costing und Prozesskostenrechnung.* Thesis. München: Vahlen Verlag.
Seuring, S. 2001. Green Supply Chain Costing - Joint Cost Managemnt in the Polyester Linings Supply Chain. *Greener management International*3: 71-80.
Seuring, S. and M. Goldbach (Eds.). 2002. *Cost Management in Supply Chains*. Heidelberg: Physica-Verlag.
Seuring, A. 2002. Supply Chain Costing - A Conceptual Framework. In: *Cost Management in Supply Chains*, edited by S. Seuring and M. Goldbach, 15-30. Heidelberg: Physica-Verlag.
Seuring, S. 2002. Supply Chain Target Costing - An Apparel Industry Case Study In: *Cost Management in Supply Chains,* edited by S. Seuring and M. Goldbach, 111-125. Heidelberg: Physica-Verlag.
Seuring, S. 2003. *Life Cycle Costing: Some Remarks From Different Perspectives.* Discussion Paper. Oldenburg: SETAC LCC Working Group.
Shapiro, K.G. 2001. Incorporating Costs in LCA. *International Journal of Life Cycle Assessment* 6(2): 121-123.
Sheriff, Y.S. and W.J. Kolarik. 1981. Life-Cycle Costing - Concept and Practice. *Omega-International Journal of Management Science* 9(3): 287-296.
Sheriff, Y.S. 1982. An Optimal Maintenance Model for Life-Cycle Costing Analysis. *Reliability Engineering & System Safety* 3(3): 173-177.
Smith, M., J. Whitelegg and N. Williams. 1997. Life Cycle Analysis of Housing. *Housing Studies* 12(2): 215-229.

Smith, V. Kerry. 1999. Substitution and Social Discount Rates: Comments on Dasgupta, Mäler, and Barrett. In: *Discounting and Intergenerational Equity,* edited by P.R. Portney and J.P. Weyant, 79-85.Washington: Resources for the Future.

Söderholm, P. and T. Sundqvist. 2003. Pricing environmental externalities in the power sector: ethical limits and implications for social choice. *Ecological Economics* 46(3):333-350.

Spash, C.L. 1993. Economics, ethics, and long-term envrironmental damages. *Environmental Ethics* 15: 117-132

Spash, C.L. and N. Hanley. 1995. Preferences, information and biodiversity preservation. *Ecological Economics* 12: 191-208.

Standards Australia and Standards New Zealand. 1999. *Life Cycle Costing: an Application Guide.* Homebush; Wellington: Standards Australia and Standards New Zealand.

Stirling, A. 1997. Limits to the value of external costs. *Energy Policy* 25 :517-540

Stuart, J.A., L.J. Turbini and J.C. Ammons. 1999. Activity-Based Environmental Inventory Allocation. *Journal of Industrial Ecology*2(3): 95-108.

Tinbergen, J. 1961. *De econonische balans van het Deltaplan [The economic balance of the Deltaplan].* Report Deltacommisie. Den Haag: Staatsdrukkerij.

Toman, M.A. 1999. Reconciling Philosophy and Economics in Long-Term Discounting: Comments on Arrow and Weitzman. In: *Discounting and Intergenerational Equity*, edited by P.R. Portney and J.P. Weyant, 31-35.Washington: Resources for the Future.

Upchurch, A. 2002. *Cost Accounting : Principles and Practice.* Harlow: Pearson Education.

USEPA. 1995. *An Introduction to Environmental Accounting As A Business Management Tool: Key Concepts and Terms.* EPA report 742-R-95-001. Washington: USEPA

USEPA. 1996. *Valuing Potential Environmental Liabilities for Managerial Decision-Making: a Review of Available Techniques.* EPA report EPA 742-R-96-003. Washington, DC: USEPA, Office of Pollution Prevention and Toxics.

Verschueren, G.L.B. 1992. *Milieu-Economische Modellen voor het Beheren van Mlieukosten [Environment-Economic Models for the Control of Environmental Costs].* TNO-rapport R92/119. Delft: TNO-Milieu en Energie, Studiecentrum voor Milieu-onderzoek TNO (SCMO).

Vicini, G. 1996. Environmental Management Accounting Revisiting the Economics of Pollution Prevention Investments. *Fondazione Eni Enrico Mattei Newsletter,* January 1996, 5 p.

Vijverberg, C.H.T.,[et al.]; Werkgroep Methodiek Milieukosten. 1994. *Methodiek Milieukosten: Achtergronddocument [Methodology Life Cycle Costing: Background Document].* Publikatiereeks milieubeheer nr. 1994/1. Den Haag: Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer.

Weitz, K.A., J.K. Smith and J.L. Warren. 1994. Developing a Decision Support Tool for Life Cycle Cost Assessment. *Total Quality Environmental Management* (autumn): 23-36.

Westkamper, E, L. Alting and G. Arndt. 2001. Life Cycle Management and Assessment: Approaches and Visions Towards Sustainable Manufacturing. *Proceedings of the Institution of Mechanical Engineers Part B - Journal of Engineering Manufacture* 215(5): 599-626.

White, A.L., D. Savage and K. Shapiro. 1996. Life Cycle Costing: Concepts and Applications. In: *Environmental Life-Cycle Assessment,* edited by M.A. Curran, 7.1-7.19. New York: McGraw Hill.

Widiyanto A, S. Kato S and N. Maruyama. 2002. A LCA/LCC Optimized Selection of Power Plant System with Additional Facilities Options. *Journal of Energy Resources Technology transactions of the ASME* 124(4): 290-299.

Wind, M. 1996. *Milieukosten en -baten, een Inleiding [Environmental Costs and Benefits, an Introduction].* TNO-rapport STB/96/008. Apeldoorn: TNO Studiecentrum voor Technologie en Beleid.

Woodward, D.G. 1997. Life Cycle Costing: Theory, Information, Acquisition and Application. *International Journal of Project Management* 15(6): 335-344.

Wrisberg, N., H.A. Udo de Haes, U. Triebswetter, P. Eder and R. Clift. 2002. *Analytical Tools for Environmental* Design and Management in a Systems Perspective. *Series Eco-Efficiency in Industry and Science. Dordrecht: Kluwer Academic Publishers.*

Wübbenhorst K.L. 1986. Life Cycle Costing for Construction Projects. *Long Range Planning*19(4):?

Young, M. 1994. *Readings in Management Accounting*. New Yersey: Prentice Hall

Yu-Lee, R.T. 2001. *Explicit Cost Dynamics: an Alternative to Activity-Based Costing.* New York [etc.]: Wiley.

Zayed, T.M., L.-M. Chang and J.D. Fricker. 2002. Life-Cycle Cost Analysis using Deterministic and Stochastic Methods: Conflicting Results. *Journal of Performance of Constructed Facilities* 16(2): 63-74.

Zehbold, C. 1996. *Lebenszykluskostenrechnung [Life Cycle Cost Analysis].* Thesis. Wiesbaden: Gabler Verlag.

Zhang ,Y., H.P. Wang and C. Zhang. 1999. Green QFD-LI: A Life Cycle Approach for Environmentally Conscious Manufacturing by Integrating LCA and LCC into QFD Matrices. *International Journal of Production Research* 37(5): 1075-1091.

Annex 4 Abstracts of Life Cycle Costing literature, exemplary

Beaver, C. (2000). LCA and Total Cost Assessment. In: *Environmental Progress* 19 (2): 130- 139.
Projects related to Total Cost Assessment and Life Cycle Analysis have been underway for four years within the American institute of Chemical Engineer's (AIChE) Center for Waste Reduction Technologies (CWRT). The effort has culminated in a fully automated Total Cost Assessment tool called TCAce(TM).

Emblemsvåg, J. (2003). *Life-Cycle Costing : Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks*. Hoboken, N.J: Wiley.
Most cost management efforts concern understanding the past but this book focuses on future costs, their uncertainties, and risks. It presents a new approach toward Life Cycle Costing based on the principles of Activity-Based Costing, uncertainty and risk management, and Monte Carlo methods. This book provides a how to methodology and shows readers that they can perform any type of cost management better than before if they introduce uncertainty into their models and exploit to the maximum what happens.

Emblemsvåg, J. & B. A. Bras (1997). A Method for Life-Cycle Design Cost Assessments using activity-Based Costing and Uncertainty. In: *International Journal of Design Automation,* 3 (4): 339-354.
A growing concern about the environment has spurred the design of more environmentally benign products and processes. For businesses, the cost of such environmentally benign products and processes is of critical importance. In this paper, a method for establishing an Activity-Based Costing with Uncertainty (ACU) model for use in life-cycle design is described. The crux is to identify the activities that will be present in the life-cycle of a product, and afterwards assign reliable cost drivers to the activities. Throughout the whole process of identifying cost drivers and consumption intensities, uncertainty distributions are assigned to the numbers used in the calculations, representing the uncertainty in the model. The inherent uncertainty is handled by employing a numerical simulation technique - the Monte Carlo simulation technique - to simulate the behavior of the model. The shape of these distributions could be based on historical data or on a designer's insight. The inclusion of these uncertainties in the model has the advantage that more true to nature assumptions are made. In addition, Activity-Based Costing (ABC) facilitates the tracing of the effects of these uncertainties through the activity network. By tracing the influence of the uncertainty and variability through the activity network, it may be noted that some uncertainties have an insignificant effect and no further data or information gathering has to be undertaken. The method is highlighted in an illustrative example where a car maker faces legislation that will force a take back of cars after a car's useful life has ended and wants to know the cost or profit involved in recycling a car under presence of uncertainty.

Gray, R. & J. Bebbington (eds.) (2001). *Accounting for the Environment*. 2nd ed. London [etc.]: Sage. 1st ed.: 1993.
Contents: Introduction of the Issues - Business and the Environment: The Challenge for Accounting and Finance - Business and the Environment: Agenda, Attitudes and Actions Management, Information and Accounting -Greening of the Organization: Getting Started 4 Environmental Policy: Adoption, Establishment and Implementation -Environmental Audits: Assessment, Review, Management and Attestation -Accounting and the Control of Energy Costs -Accounting and Controlling for the Costs of Waste, Recycling and Packaging -Investment, Budgeting and Appraisal: Environment at the Heart of the Accounting and Financial System -Life Cycle Analysis and Assessment External Relations -The Greening of Finance: Bank Lending, Insurance and Ethical/Environmental Investment -External Reporting and Auditing I: Reporting within a Financial Framework -External Reporting and Auditing II: Non-Financial

Reporting -External "Social Audits" Future Directions -Accounting and Reporting for a Future: Sustainability, Accountability and Transparency -A Change of Paradigm?

Kreuze, J. G. & G.E. Newell (1994). ABC and Life-Cycle Costing for Environmental Expenditures. In: Young, M. (ed.), *Readings in Management Accounting*, 62-67. New Yersey: Prentice Hall. Also published in Management Accounting, (February 1994), 38-42.
This reading examines accounting for environmental expenditure. Two areas focused upon are life-cycle costing and activity based costing (ABC). The allocation of cost is a contentious issue in accounting, for it directly influences profit, but more importantly it influences the profit for specific products or activities. This article examines the means by which costs can firstly be identified and second, be appropriately allocated. Life-cycle analysis or life-cycle costing is a useful tool in identifying costs that may be incurred in future periods (and therefore may be neglected under many circumstances). ABC is one means by which costs can be allocated to specific activities. For those that have already undertaken the accounting module you may wish to reflect on the module on cost allocation.

National Defense Center for Environmental Excellence (NDCEE) (1999). *Environmental Cost Analysis Methodology ECAM Handbook*. Fairfax, VA, USA: Concurrent Technologies Corporation.
The U.S. Department of Defense (DOD) is demonstrating and validating promising, innovative technologies that target urgent environmental needs. In addition to being environmentally preferred, these technologies provide a return on investment through cost savings and improved efficiency. The Office of the Deputy Under Secretary of Defense for Environmental Security (DUSD-ES) tasked Concurrent Technologies Corporation (CTC), through the National Defense Center for Environmental Excellence (NDCEE), in cooperation with Coopers & Lybrand, L.L.P., to design a method for making consistent and reliable environmental investment and project selection decisions. In response, the Environmental Cost Analysis Methodology (ECAM) was developed to provide a consistent means of quantifying and evaluating environmental costs and benefits. The ECAM is a tool for evaluating investments in environmental technologies that address compliance and pollution prevention issues. The ECAM was validated at Lake City Army Ammunition Plant (LCAAP), Independence, Missouri, where an ammunition manufacturing process is being modified to reduce the use of hazardous materials. The ECAM has been applied at five DOD locations in which environmentally preferred technologies have already been fielded or are being evaluated for future use. Each of these technologies is designed to eliminate or reduce potentially adverse environmental impacts, while simultaneously cutting costs and maintaining or improving product quality.
The ECAM is a capital investment decision tool used by process engineers, with input from facility accounting personnel, to perform economic analyses-especially when environmental costs are a factor. The ECAM was developed to provide a consistent means of quantifying and evaluating environmental costs and benefits. The ECAM was designed to evaluate environmental technologies that address compliance and pollution prevention issues. The ECAM was not designed as a life cycle costing tool to evaluate new systems over the entire weapon system life cycle, rather it was designed to evaluate individual process technologies fielded in the operations and support phase. The ECAM focuses primarily on quantifying and evaluating costs associated with the selected environmental technology. Qualitative issues are also addressed by the ECAM, but to a lesser extent. The scope of the ECAM is presently limited to facility-specific cost information and does not quantify future environmental liability costs or intangibles such as opportunity costs, quality of life, and resource depletion. It is anticipated that revised versions of the tool will be released following further validation.

USEPA (1996), *Valuing Potential Environmental Liabilities for Managerial Decision-Making: a Review of Available Techniques*. EPA report EPA 742-R-96-003. Washington, DC: USEPA, Office of Pollution Prevention and Toxics.
Companies are increasingly aware of the environmental aspects of their businesses. More and more managers want to consider the beneficial and adverse environmental implications of their business

activities, products, and services. These "implications" include impacts on environmental conditions, associated financial effects, corporate image consequences, and significance for business strategy. However, some companies have found it difficult to measure these implications, both because of the inherent uncertainties in measuring them, and because existing information, planning, and decision-making practices do not highlight those implications sufficiently.
To address those obstacles, companies have begun to use environmental evaluation techniques such as life cycle analysis (LCA), environmental life cycle costing (ELCC), and total cost assessment (TCA). Environmental cost accounting techniques such as TCA and ELCC are used to demonstrate the potential for environmentally-beneficial investments to yield significant financial pay-offs. One such pay-off is the avoidance of environmental liabilities. If this benefit is overlooked, environmental investments may appear less attractive than they truly are. The same logic applies to operating, design, and other business decisions that are not viewed as primarily "environmental" in nature. Businesses can prevent or reduce environmental liabilities by, first, paying attention to the environmental aspects of their business decisions and operations, and, second, translating the liabilities into monetary terms so they can more easily be made a part of financial evaluations. The Environmental Protection Agency (EPA) is issuing this report as a step toward helping companies assess and manage their environmental liability costs. The report describes valuation approaches and tools that have been specifically developed or adapted for estimating environmental liability costs for consideration in business management decisions such as capital investments, process/input substitutions, product retention and mix, facility siting, and waste management. The emphasis in this report is on techniques for placing a monetary value on potential, preventable environmental liabilities. Sources of information on estimating environmental liability costs are somewhat obscure; EPA thus offers this summary of documented valuation techniques to managers who are interested in estimating potential environmental liability costs, but are unaware of techniques to do so. While estimation techniques are still under development, and possibly controversial, this report is intended to assist organizations to estimate future and/or potential environmental liability costs within reasonable limits of accuracy such that a manager is comfortable using the estimations when making decisions.

Arnse, K. (1997). De industrie en het Milieu : Hogere Milieukosten, Maar Minder Druk op het Milieu *[The Industry and the Environment: higher environmental Costs, but less Pressure on the Environment]*. In: *Industriemonitor*, 2: 6-10.
Artikel presenteert de milieu-investeringen, de milieukosten en -lasten (naar milieucompartiment) voor de hele industrie en per bedrijfsklasse over de jaren 1984-1993. Voorts wordt een overzicht van de druk op het milieu door de totale industrie voor de jaren 1984-1993 gegeven.

Badgett, L., B. Hawke & K. Humphrey (1995). *Analysis of Pollution Prevention Investments Using Total Cost Assessment: a Case Study in the Electronics Industry*. Seattle, WA: Pacific Northwest Pollution Prevention Research Center.
The main objective of this project was to identify an effective decision-making method for small firms evaluating the costs and benefits of pollution prevention opportunities. Six decision-making tools were assessed for their flexibility, resource requirements, and capacity to generate economic data. Research identified Total Cost Accounting (TCA) as the most useful and practical tool for small manufacturers. A case study applying TCA confirms the method's effectiveness. Some general findings related to TCA are:
- TCA provides a streamlined approach to identifying and quantifying costs and benefits of pollution prevention investments.
- TCA expands the scope of capital budgeting to include indirect benefits, increasing the magnitude of savings derived from pollution prevention investments. The five-year savings associated with the investments analyzed in this report totaled more than $95,000.
- In most cases, collecting data for TCA analysis requires input from a number of departments. Small businesses using the TCA approach will find it easier to implement if a variety of disciplines are involved in the data collection process.

- TCA is flexible; it accommodated analysis of two distinct projects. It seems feasible that the TCA framework could be easily applied to other investments and or industries
Although small firms have resource constraints, this project demonstrated that the TCA framework is flexible and practical. The small manufacturer studied expects to replicate the TCA analysis to evaluate future pollution prevention opportunities. The TCA framework will help the study subject, as well as other small manufacturers, make better investment decisions, both economically and environmentally.

Bage G.F. & R. Samon (2003). The Econo-Environmental Return (EER) - A Link between Environmental Impacts and Economic Aspects in a Life Cycle Thinking Perspective.
In: *International Journal of Life Cycle Assessment* 8 (4): 246-251.
Many analytical tools have been developed to support the implementation of sustainable development. Principal among these are the ones that are based on physical aspects such as life cycle assessment (LCA), while others focus on non-physical aspects, namely on monetary concepts, such as life cycle costing and total cost assessment. Each kind of tool is designed to assess a specific aspect (environmental or economic) of the entire life of a good or a service. Unfortunately, even if the literature clearly states the advantage of combining these tools, case studies with global conclusions considering both aspects are still rare. Most often, studies conclude separately on each aspect; environmental impact and cost assessment. Definitions. The already published concept of Return on Environment (ROE), inspired from return on investment, is a first step in the right direction for combining these tools and hence, achieving better alternative comparisons. Considering some limitations as to the ease with which it compares two or more similar goods, two new indexes are suggested here. The first one, called the Environmental Return (ER), focuses only on environmental aspects. It allows the comparison on an environmental basis of several goods or services fulfilling the same function. The second definition, called the Econo-Environmental Return (EER), is an index created by the combination of the environmental impact assessment results (such as an LCIA) and those from an economic assessment (such as an LCC or a TCA). From a simple decision rule, a decision-maker can compare several goods on both environmental and economic aspects. Discussion and Conclusion. A simplified case study is used to present a numerical application interpret their different results and conclusions. Two different types of broadloom carpet, PET (recycled polyester) and nylon, are compared. When they are only compared on an LCIA basis, the PET carpet is preferred over the nylon one, while the opposite is true when they are compared on both economic aspect and environmental impact bases. The major advantage of the Econo-Environmental Return is that two goods can be compared without requiring a specific industrial sector reference value.

Bartlett E. & N. Howard (2000). Informing the Decision Makers on the Cost and Value of Green Building. In: *Building Research and Information*, 28 (5-6): 315-324.
This paper seeks to challenge the traditional way in which we assess the value of green buildings in terms of their environmental friendliness, energy efficiency and whole life cost. In the UK, quantity surveyors (or cost consultants) have a perception that more energy efficient and environmentally friendly buildings cost between 5% and 15% more to build from the outset. This common assumption is not backed up by recent research and should be questioned. Construction professionals need to be informed of the whole life cost and environmental impact of buildings so that they can encourage key stakeholders to make more sustainable choices. These emerging issues together with practical tools are considered with case studies from recent projects.
Author Keywords: green buildings, economics, life-cycle costing, property, environmental performance, finance, clients, cost estimates, investors, UK

Behrens, M.L., B.I. Dvorak & W.E. Woldt (2000). Implications of hidden costs: Comparison of Bitumen Testing Procedures. In: *Environmental Technology* 21 (3): 243-255.
Traditional cost analyses used for process cost comparisons often ignore costs (e.g., waste disposal, regulatory compliance, long-term liabilities) that are lumped into general overhead but actually are incurred during the process. In this research, both a traditional cost analysis and a total cost assessment

(which includes many often-neglected process costs) were performed on five potential methods of testing the bitumen composition of newly paved asphalt. In the past, the bitumen contact of asphalt pavement was determined by tests using toxic solvents; alternative, less polluting methods have been developed that can replace the traditional solvent extraction method. In order to represent the uncertainties in the design and cost data (especially the liability costs) for this cost comparison, fuzzy set theory was used. A traditional economic analysis that included only the capital and operating and maintenance costs found that the most environmentally friendly process (ignition ovens) was only slightly less costly than two other options. The cost of the ignition ovens and two other options were similar enough to be considered within the range of uncertainty for the analysis. However. when the hidden costs related to the environmental, health, and safety aspects for a bitumen testing procedure were incorporated into the cost analysis, the cost comparison changed significantly; the most environmentally-friendly option, ignition ovens, was shown to be by far the least-cost option. Thus, incorporating hidden environmental costs into a cost analysis can have a significant impact.

Bennett, M. & P. James (contrib. Ed.) (1998). *The Green Bottom Line: Environmental Accounting for Management, Current Practice and Future Trends*. Sheffield: Greenleaf Publishing.
To date, both internal and external corporate environmental reporting and management systems have focused on physical input-output measures. However, external stakeholders are increasingly demanding that organizations provide more financial information about the costs and benefits of their environmental actions.
As environmental costs rise, internal decision makers are also seeking such information to ensure that money is well spent. Beyond basic compliance, many companies will not countenance environmental actions for which a "business case" cannot be made.
A number of companies such as Baxter, BT, Xerox, Zeneca, and others are now beginning to develop a better understanding of the costs and benefits of environmental action. The US Environmental Protection Agency has also done considerable work on models designed to understand the "full costs" of pollution control investments, with the aim of demonstrating that -- when these are properly considered -- pollution prevention can be a more cost-effective alternative.
The Green Bottom Line brings together much of the world's leading research and best-practice case studies on the topic. Divided into four sections, covering "General Concepts," "Empirical Studies," "Case Studies," and "Implementation," the book includes case studies from the US EPA's Environment Accounting Program and contributions from authors at institutions including the IMD, INSEAD, Tellus Institute, and the World Resources Institute. It constitutes a state-of-the-art collection.

Centraal Bureau voor de Statistiek, (1979-). *Milieukosten van bedrijven ... [Environmental Costs of Companies*]. Voorburg: CBS.
Gegevens betreffende de milieukosten van bedrijven. Milieu-investeringen naar bedrijfsklasse, milieucompartiment, grootteklasse aantal werkzame personen. Water, lucht, bodem, afval, geluid, landschap: kosten van eigen milieu-activiteiten naar kostensoort (en type verontreiniging). Betaalde en toegerekende milieuheffingen en -leges. Betalingen aan derden voor de afvoer van afvalstoffen. Netto milieulasten naar milieucompartiment, in relatie tot enkele bedrijfskenmerken, exclusief algemene brandstofheffing. Milieu-investeringen van bedrijven met 5-19 werkzame personen.

Cole, R.J. & E. Sterner (2000). Reconciling Theory and Practice of Life-Cycle Costing. In: *Building Research and Information*, 28 (5-6): 368-375.
The notion of Life-Cycle Costing (LCC) is generally recognized as a valuable approach for comparing alternative building designs - enabling operational cost benefits to be evaluated against any initial cost increases. However, a host of practical difficulties conspire to limit its widespread adoption. This limited acceptance is particularly important in green building where many of the benefits of strategic choices can often only be understood and justified when cast in a life-cycle context. This paper identifies some of the

critical gaps between the theory (and promise) and practice of Life-Cycle Cost analysis to discover strategies that encourage greater use.

Edwards. S., E. Bartlet & I. Dickie (2000). ***Whole Life Costing and Life-Cycle Assessment for Sustainable Building Design.*** **Building Research Establishment digest. 452. [S.l.]: Building Research Establishment.**
The integration of Whole Life Costing (WLC) and Life-Cycle Assessment (LCA) presents a powerful route to improving the sustainability of the construction industry. Combining economic and environmental assessment tools to obtain 'best value' solutions in both financial and environmental terms has the potential to make a significant contribution to achieving sustainable building design. This Digest describes the issues relating to the use of the two tools and goes on to provide examples from a number of recent projects

Finch, E.F. (1994). The Uncertain Role of Life-Cycle Costing in the Renewable Energy Debate. In: ***Renewable Energy*** **5 (5-8): 1436-1443.**
In a decade when environmental issues have become prominent, the significance of 'aftercare' has struck a chord with many stake holders in the building process. None more so than clients who are mindful of inheriting a building that will incur costs long after hand-over. Energy saving has served the interest of the client as well as the global concerns of society at large. Cost savings provide a strong incentive and may not conflict with environmental objectives.
Other energy conscious measures may not result in direct cost savings for the client. To foster these solutions, two strategic approaches apply; either make greater demands on the benevolence and responsibility of clients; or adopt an adversarial approach of legislative control over the design of facilities. The former is clearly a more desirable approach. However, the client still needs a framework for making realistic environmental decisions within the context of other competing business constraints. This paper describes how life cycle costing can be changed to meet just such a need Ih. this way, clients will be able to make more informed decisions concerning environmental impacts.

Helberg, C., J.E. Galletly & J.R. Bicheno (1994). Simulating Activity-Based Costing. In: ***Industrial Management & Data Systems*****, 94 (9): 3-8.**
Many traditional cost accounting methods can result in distorted cost information as they allocate overheads in proportion to labour. This can result in a low technology product being overcosted and a high technology product being undercosted. Activity-based costing (ABC) allocates costs more accurately and pinpoints areas of waste. Describes software which provides a tutorial introduction to ABC and highlights the difference between ABC and conventional cost accounting by means of simulating a production environment for the user to explore. The simulator should foster improved understanding of the opportunities of ABC.

Kane, G., J.L. Stoyell, C.R. Howarth, P. Norman & R.Vaughan (2000). A Stepwise Life Cycle Engineering Methodology for the Clean Design of Large Made to Order Products. In: ***Journal of Engineering Design*****, 11 (2): 175-189.**
This paper describes the stepwise life cycle engineering methodology for the clean design of large made to order (LMTO) products under development at the Engineering Design Centre, University of Newcastle upon Tyne, UK. LMTO products, such as offshore platforms, ships and power stations, have particular environmental implications due to their size, cost, long life spans, high public visibility and their potential for ecological/civil disaster. The methodology uses a stepwise approach to apply life cycle costing, life cycle assessment (environmental impact estimation) and risk assessment to an inventory model of the product. Both the inventory model and the analyses increase in complexity as the design progresses. The methodology extends the LMTO product life cycle model to include a long-term 'legacy' phase to address the intergenerational equity principle of sustainable development.

Klopffer, W. (2003). Life-Cycle Based Methods for Sustainable Product Development. In : *International Journal of Life Cycle Assessment,* 8 (3): 157-159.
Sustainability-a term originating from silviculture, which was adopted by UNEP as the main political goal for the future development of humankind-is also the ultimate aim of product development. It comprises three components: environment, economy and social aspects which have to be properly assessed and balanced if a new product is to be designed or an existing one is to be improved. The responsibility of the researchers involved in the assessment is to provide appropriate and reliable instruments. For the environmental part there is already an internationally standardized tool: Life Cycle Assessment (LCA). Life Cycle Costing (LCC) is the logical counterpart of LCA for the economic assessment. LCC surpasses the purely economic cost calculation by taking into account hidden costs and important point that different life-cycle based methods (including Social Life Cycle Assessment) for sustainablity assessment use the same system boundaries.

Lippiatt, B.C & A.S. Boyles (2001). Using BEES to Select Cost-Effective Green Products In: International Journal of Life Cycle Assessment, 6 (2): 76-80.
The BEES (Building for Environmental and Economic Sustainability) software brings to your fingertips a powerful technique for balancing the environmental and economic performance of building products. The tool is based on consensus standards and designed to be practical, flexible, and transparent. Version 2.0 of the Windows(TM)-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 65 building products. The purpose is to support purchasing decisions by providing key science-based information often lacking in 'green' product selection. The intended result is a cost-effective reduction in building-related contributions to environmental problems.

Partovi, F.Y. (1991). An Analytic Hierarchy Approach to Activity-Based Costing. *In: International Journal of Production Economics*, 22 (2): 151-161.
This article presents an estimating model for determining how overhead costs might be allocated to different products. The model, which is loosely based on Activity-Based Costing (ABC), incorporates Saaty's Analytical Hierarchy Process (AHP) in estimating the overhead costs associated with each product. The proposed model uses overhead cost categories, and other cost-correlated information, as well as managers' subjective judgments for detail classification of overhead costs when "hard" data are not available. This model allows business to determine the benefits of ABC before actual implementation. A real-world example illustrates the model.

Roodvoets, D.L. (2003). Reducing Life-Cycle Costs. In: *College Planning and Management,* 6 (8): 8-10.
Presents factors to consider when determining roofing life-cycle costs, explaining that costs do not tell the whole story; discussing components that should go into the decision (cost, maintenance, energy use, and environmental costs); and concluding that important elements in reducing life-cycle costs include energy savings through increased insulation, reduced maintenance costs through design and system protection, and reuse or recycling at the end of the systems useful life.

Schaltegger, S. (1997). Economics of Life Cycle Assessment: Inefficiency of the Present Approach.In: *Business Strategy and the Environment*, 6:1-8.
From an economic perspective, tools of environmental management must be eco-efficient, i.e. they have to be economically efficient and they must lead to ecologically sound decisions. Life cycle assessment (LCA) is regarded as one of the most important environmental management tools today. It attempts to record and assess all the environmental impacts of the whole life cycle of a product. The potential benefits of LCA have been discussed extensively. However, the costs and the effects actually achieved have been vastly neglected. Economic analysis shows that the present approach of LCA is economically inefficient

compared with site-specific environmental management and that it is likely to result in ecologically wrong decisions.

Sekhar, S.C. & K.L.C. Toon (1998). On the Study of Energy Performance and Life Cycle Cost of Smart Window. In: *Energy and Buildings* 28 (3): 307-316.
With worldwide energy cost rising significantly, there has been a pressing need to reduce the burning of fossil fuels and subsequently energy consumption. This, coupled with the prospect of global warming threatening human habitation, has made countries including Singapore more conscious and aware of the energy problem at hand. This paper deals with smart window, a double glazing unit where one pane consists of a high-performance heat reflective glass and the other coated with low-emissivity (low-e) coating. This combination of glazing provides optimum energy efficiency and a high level of daylight transmission with minimal reflectance. A study is made on the benefits derived from smart window done on a hypothetical 20-storey building. This encompasses a description of its quantitative impact on cooling load, energy consumption and energy savings achieved as compared with other forms of glazing. Following this, a detailed life cycle costing is done to determine the economic benefits attained from this type of glazing. The reduction of atmospheric pollutants as a result of using smart window is also analysed, and the future application of the glazing in hot and humid climates is discussed. In conclusion, it is observed that the smart window meets the technical and economic targets set, thus making it a viable long-term investment for high-rise commercial buildings.

Shapiro, K.G. (2001). *Incorporating Costs in LCA*. In: International Journal of Life Cycle Assessment, 6 (2): 121-123.
The goal of LCA is to identify the environmental impacts resulting from a product, process, or activity. While LCA is useful for evaluating environmental attributes, it stops short of providing information that business managers routinely utilize for decision-making - i.e., dollars. Thus, decisions regarding the processes used for manufacturing products and the materials comprising
those products can be enhanced by weaving cost and environmental information into the decision-making process. Various approaches have been used during the past decade to supplement environmental information with cost information. One of these tools is environmental accounting, the identification, analysis, reporting, and use of environmental information, including environmental cost data. Environmental cost accounting provides information necessary for identifying the true costs of products and processes and for evaluating opportunities to minimize those costs. As demonstrated through two case studies, many companies are incorporating environmental cost information into their accounting systems to prioritize investments in new technologies and products.

Smith, M., J. Whitelegg & N. Williams (1997). Life Cycle Analysis of Housing. In: *Housing Studies* 12 (2): 215-229.
Abstract: This paper reports the findings of a project to assess the costs and benefits of adopting environment-friendly construction practices for social rented housing in Scotland. Two contrasted dwelling specifications-one for a conventional building (the Control) and one for an environmentally responsible building (Eco-Type 1)-are compared using Life Cycle Analysis and Life Cycle Costing methodologies. An assessment is made of the environmental and economic implications of adopting environmentally conscious construction practices in social rented housing. If is concluded that the provision of environmentally responsible dwellings could bring large-scale reductions in the environmental burden of housing, and economic savings for housing providers and tenants over the life cycle of a dwelling with only a small increase in capital costs.

Westkamper, E, L. Alting & G. Arndt (2001). Life Cycle Management and Assessment: Approaches and Visions Towards Sustainable Manufacturing. In *Proceedings of the Institution of Mechanical Engineers Part B - Journal of Engineering Manufacture*, 215 (5): 599-626.
Thinking in terms of product life cycles is one of the challenges facing manufacturers today: efforts to

increase efficiency throughout the life cycle do not only mean extended responsibility of the parties concerned. Economically successful business areas can also be explored. Whether new service concepts are required, new regulations have been passed or consumer values are changing, the differences between business areas are disappearing. Life cycle management (LCM) considers the product life cycle as a whole and optimizes the interaction of product design, manufacturing and life cycle activities. The goal of this approach is to protect resources and maximize effectiveness by means of life cycle assessment, product data management, technical support and, last but not least, life cycle costing. This paper shows the existing approaches of LCM and discusses their prospects and further development.

Widiyanto A, S. Kato S & N. Maruyama (2002). A LCA/LCC Optimized Selection of Power Plant System with Additional Facilities Options. In: *Journal of Energy Resources Technology transactions of the ASME*, 124 (4): 290-299.
In the past, the selection of all energy resource for electricity generation was dominated by finding the least expensive power generating plant. Although such all approach is essential, there is growing concern about other aspects of power generation such as social, environmental and technological benefits and consequences of the energy source selection. The aims of this paper are first to introduce a life cycle assessment (LCA) scheme with the aid of the NETS (Numerical Eco-load Total Standardization) method that we have newly proposed. This method provides a numerical measure for evaluating the quantitative load of any industrial activity on the environment, and has been used to analyze the energy flow and the environmental loads of various power generation systems. A second goal is to develop a computer program to examine the applicability, of technology options based oil cost performance and environmental load reduction. A filial goal of this work is to select the power system using life cycle assessment (LCA) and life cycle costing (LCC). As a result, environmental load and economical cost for various power generation systems are discussed from the LCA point of view for further ecological improvement.

Zhang ,Y, H.P. Wang & C. Zhang (1999). Green QFD-LI: A Life Cycle Approach for Environmentally Conscious Manufacturing by Integrating LCA and LCC into QFD Matrices. In: *International Journal of Production Research,* 37 (5): 1075-1091.
Green Quality Function Deployment-II (GQFD-II), a new methodology for product development or improvement, is introduced in this paper. By integrating Life Cycle Costing (LCC) into QFD matrices and deploying quality, environmental and cost requirements throughout the entire product development process, GQFD-II elaborates the original GQFD, in which Life Cycle Assessment (LCA) and QFD are combined to evaluate different product concepts. GQFD;II includes three major phases. Phase I-Technical Requirement Identification. Quality house, green house and cost house are established in this phase, where customer, environmental and cost requirements are established and documented. Phase II-Product Concept Generation. A series of product concepts are generated to satisfy the requirements established from Phase I. These concepts can be evaluated with respect to quality, environment and cost. The best product concept is then selected. Phase III-Product/Process Design. In this phase, the requirements from previous phases are deployed into all product/process design stages, so that a series of matrices can be established, including: design deployment, process planning, production planning, maintenance planning, and retirement planning. In this paper, an illustrative example (engine filters) is used to demonstrate the concept of GQFD-II.

Annex 5 Tools

http://teexcit.tamu.edu/tca/ is an on line course on TCA.

http://www.dep.state.pa.us/dep/deputate/pollprev/Tech_Assistance/toolbox/costacct.htm has references to several tools for cost accounting.

http://akss.dau.mil/software/56.jsp ***DAU*** is the US *Defense Acquisition University*, which has LCC/TOC as a central element in courses and tools, both at a methods level and in terms of legal rules and procedures.