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# Life Cycle Costing, a View of Potential Applications: from Cost Management Tool to Eco-Efficiency Measurement

Francesco Testa<sup>1</sup>, Fabio Iraldo<sup>1,2</sup>, Marco Frey<sup>1,2</sup> and Ryan O'Connor<sup>2</sup>

<sup>1</sup>*Sant'Anna School of Advanced Studies, Piazza Martiri della Libertà 33, 56127 Pisa,*

<sup>2</sup>*IEFE – Institute for Environmental and Energy Policy and Economics,*

*Via Roentgen 1, 20136, Milano*

*Italy*

## 1. Introduction

In the field of modern production contexts, the complexity of processes combined with an increasingly dynamic competitive environment has created, in business management, the need to monitor and analyze, in terms of generation costs, not only the internal production phase but all stages both upstream and downstream in order to minimize the total cost of the product throughout the entire life cycle.

The approach of life-cycle cost analysis was used primarily as a tool to support investment decisions and complex projects in the field of defence, transportation, the construction sector and other applications where cost constitutes the strategic analysis of cost components of a project throughout its useful life.

The analysis methodology of Life Cycle Costing (LCC) concerns the estimate of the cost in monetary terms, originated in all phases of the life of a work, i.e. construction, operation, maintenance and eventual disposal / recovery. The aim is to minimize the combined costs associated with each phase of the life cycle, appropriately discounted, thus providing economic benefits to both the producer and the end user.

Life Cycle Costing (LCC) is a tool used in consolidated management accounting (Horngren, 2003, Atkinson et al., 2002), which aims to achieve a reduction in carbon dioxide. Whole life cost. This identifies, with reference to the system, the functional activities within the appropriate stages of design, production, use and disposal of waste, and appropriates a cost (Fabricky Blanchard, 1991) in order to clarify the causal relationship between resulting architecture of product design alternatives and cost estimates of fees, which will probably be supported by the various actors within the economic life of the product [Fixson, 2004].

Life Cycle Costing is an analytical tool and method which belongs to the set of life cycle approach. Traditionally, LCC was used to support purchasing decisions of products or capital equipment involving a large outlay of financial resources (Huppel et al., 2005). In the definition provided by Rebitzer & Hunkeler (2005) LCC incorporates all costs, both internal and external, associated with the life cycle of a product, and are directly related to one or more actors in the supply chain.

In recent years, the spread of life cycle thinking within business planning and management has led to an evolution of LCC methodology by extending the scope of integrated analysis of the three pillars comprising sustainable development - economic, environmental and social - in a financial representation.

Analysis of different applications undertaken in recent years identifies three types of Life Cycle Costing, for separate purposes and methods of application: Business LCC, Environmental LCC and Social LCC.

Business LCC, or traditional LCC, is commonly used as a method of cost analysis and business decision support in procurement and investment. Cost categories and principles that are to be followed in the measurement procedure need to be established in advance, and the functional unit is represented by just one product.

Environmental LCC in the product or system under study is usually less complex and the functional unit is chosen according to international standards as specified by ISO 14040 (i.e. 1m<sup>2</sup> of floor). Unlike the traditional LCC, it is not used as a tool for procurement decisions or control, but to analyze the environmental and economic impact of a product or system. The cost estimate is obviously simpler than what occurs in the traditional LCC approach and is usually characterized by a static (steady state). In Environmental LCC, the integration of the instrument in Life Cycle Assessment is one of the fundamental aspects.

The Social LCC is the third component of the measure of sustainable development, in addition to the LCA and Environmental LCC (Hunkeler et al., 2006). The goal is to allow the organization to conduct its business in a responsible manner by providing information on potential social impacts caused to individuals by the product during its life cycle.

The analysis of social impacts, as is the case for environmental LCC, takes into account both the internal and external costs. Internal costs are those that the various actors involved during the lifecycle of a product must support, such as production costs or the costs of use; while the external costs, also called externalities, are related to the effects of monetized environmental and social impacts generated by a given product. These costs are usually not directly borne by the consumer or derived from making or using the product, but affect the entire community indiscriminately.

The following chapter will highlight the main applications of Life Cycle Costing methodology, both as a tool for minimizing business costs for a project or a product and as an essential component of sustainability-oriented life cycle management. In the final section, we will see a short description of the possible application of LCC for the construction of eco-efficiency indicators

## **2. Business life cycle costing**

The issue of life cycle costing arrives in the context of at least two aspects: one related to the development of new products, the other in the evaluation of strategic investments (Ciroth, 2003).

The first refers to the application of Life Cycle Costing to identify, measure and evaluate the costs associated with the entire life cycle of a new product, especially in the case of complex and durable products. The second concerns the application of LCC as a tool for comparative analysis of long-term investment projects and in managing the cost of a new product.

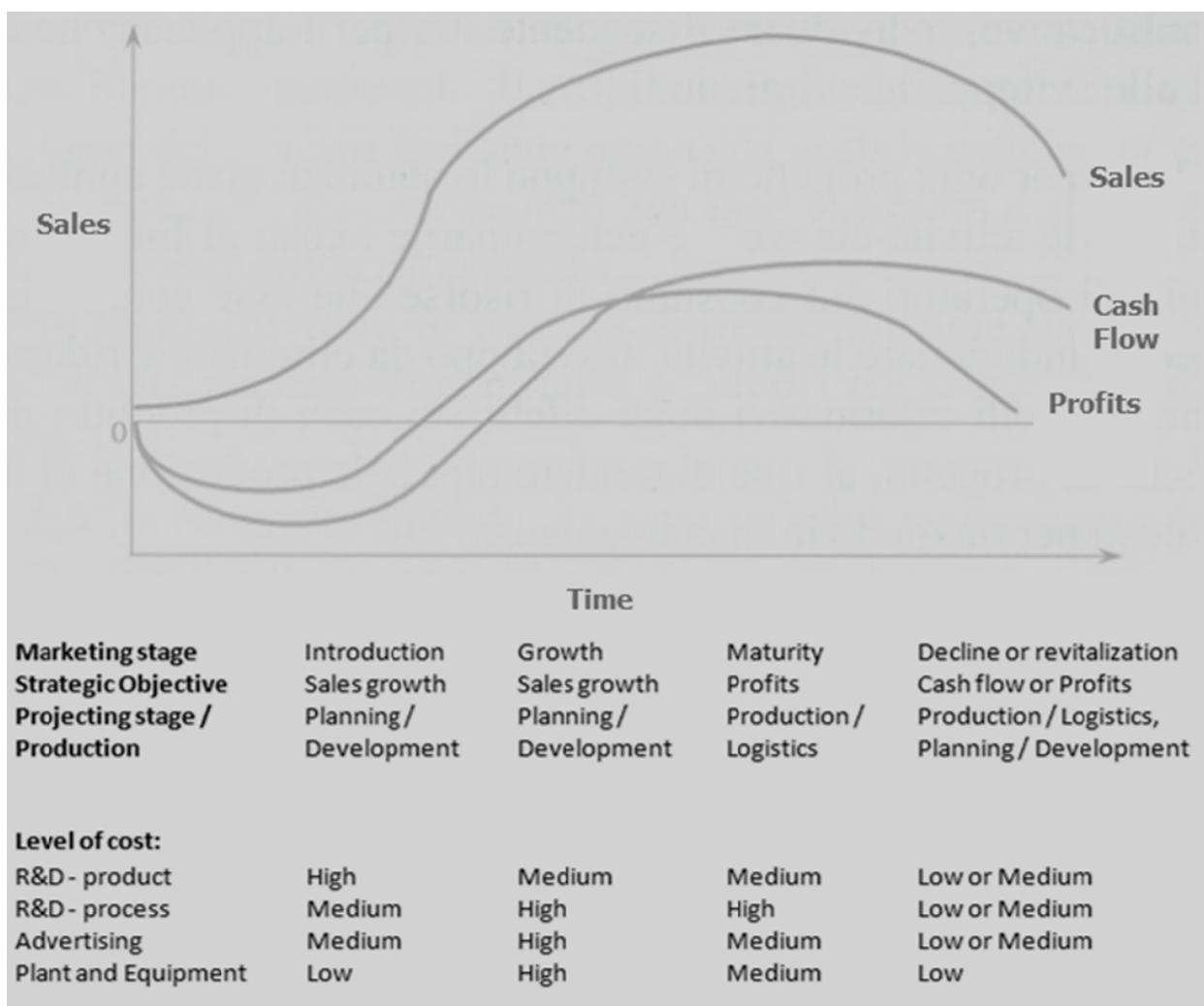
The application of LCC in the management of the product can be seen from two distinct perspectives:

1. From the economic perspective of a producer, to support management in planning and managing the product throughout its life cycle;
2. From the economic perspective of a customer, or as an aid in the purchasing stage aimed at determining the total cost for the entire life cycle.

From the perspective of the producer, calculations consist of the estimation of the costs of design, engineering, industrialization and production of a new product and in the analysis of these costs throughout the life cycle (Asiedu & Gu, 1998).

Once the life cycle duration of the product has been identified and individual cost elements produced in the various stages has been identified and measured, a detailed analysis can highlight the relationships between the individual cost items of each phase.

The decisions taken during planning and design can have an impact on the costs incurred in subsequent phases. An example can be durable consumer goods, such as appliances: the choice between different technological solutions in the design phase can strongly influence the efficiency of the product and thus reduce or increase its usage cost. Efficiency measures the relation between outputs from and inputs to a process, the higher the output for a given input, or the lower the input for a given output, the more efficient is an activity, product, or



Source: Vitali, 2004 (adapted from Susman, 1995)

Fig. 1. The life cycle of a product

business (Burrill & Saka 2006). The traditional cost accounting systems tend to focus on the production phase, underestimating the importance of cost information relating to upstream and downstream stages. An integrated view of the different phases of the lifecycle, however, show that the maximization of value added does not depend strictly on cost minimization or revenue maximization at each stage.

Following the product throughout its life cycle ensures a useful flow of information to all business functions regarding the elements that determine the success of a product, allowing them to react promptly and effectively to resolve any weaknesses. From this perspective, Life Cycle Costing moves from a mere trend costing instrument to assuming a key role in the support strategies and decisions of business management.

From the perspective of the customer, the LCC aspect of the concept of Total Cost of Ownership (TCO) is defined as a philosophy of cost calculation aimed at determining the total cost of purchase, possession and use of a particular product (Ellram, 1995). This philosophy recognizes that the purchase price represents only one component of the total cost of a product throughout its useful life and can be applied both to the process of purchasing goods and as a capital investment tool by organisations (Ellram & Sifred, 1998).

TCO, compared to traditional methods of cost analysis of the life cycle, has some distinctive features: the range of costs considered is wider considering the cost of the first purchase. Moreover, while LCC considers only the costs as quantifiable monetary values, TCO also extends to the costs associated with the low quality of a product and related services, and all the opportunity costs associated with such low quality (Pitzalis, 2003b).

A survey of consumers conducted in the 1970's by Hutton and Wilkie found that consumers who make buying decisions using the LCC approach could lead to a reduction in the consumption of energy equal to a saving of \$ 4 billion annually (Hutton and Wilkie, 1980).

The use of LCC in the procurement phase is also desirable from the economic perspective of the buyer. Taking Italy as an example, we find that the volume of public spending of Public Administration represents 17% of the Gross Domestic Product (GDP), compared to 18% on average in the EU, and 15% in the USA (Iraldo et al. 2008).

A survey conducted by ICLEI - Local Governments for Sustainability - in 2007 on behalf of the European Commission, shows how the use of LCC during purchasing would allow, for certain types of products, financial savings as well as offering significant environmental benefits.

### **3. The product lifecycle and Life Cycle Assessment (LCA)**

In recent years, different methodologies have been developed as a direct response to increasing environmental threats, in order to study and evaluate the environmental impacts associated with a product. The need to develop operational and technical management tools in this area is gained as a result of a more environmental focus and mounting pressure from external partners of the undertaking, who increasingly request guarantees regarding the environmental compatibility of products. In order to address these challenges, environmental considerations need to be integrated into a number of different types of decisions made both by business, individuals, and public administrations and policymakers (Nilsson and Eckerberg, 2007) This has prompted companies, scientific institutions and standardisation bodies (national and international) to study, develop and progressively refine methodologies that would respond to the needs of public authorities, business partners, consumers and, more generally, by all stakeholders of an organisation.

The first problem we find in the definition of methodological tools of environmental assessment is the correct measurement of the impacts as related to a product. It is known that a product passes through different stages during its lifetime: from the initial manufacture through the process of production, consumption throughout the use of the product, and finally the "death" (and disposal) with the exhaustion of its function. During each of these stages, the product has a number of impacts on the environment. The significance of these impacts may vary depending on the stage of the lifecycle that is treated; if the study of the impact, for example, is limited to a single phase, the outcome could be misleading. The main tool, available to scholars to conduct an examination congruent with the requirements mentioned, is the method known as "Life Cycle Assessment". This tool, developed to overcome these potential drawbacks, has as its focal point the performance analysis of systems, applied to assess the potential environmental impacts and resources used throughout a product's lifecycle, i.e., from raw material acquisition, via production and use phases, to waste management (ISO, 2006a).

This approach is also defined as "cradle to grave". The comprehensive scope of LCA is useful in order to avoid problem-shifting, for example, from one phase of the life-cycle to another, from one region to another, or from one environmental problem to another (Finnveden et al 2009).

LCA-methodology and the term was first coined during a SETAC (Society of Environmental Toxicology and Chemistry) conference in 1990 in Vermont (USA), and is defined as "an objective process of evaluation of environmental burdens associated with a product (...) through identifying and quantifying energy and materials used and waste released into the environment, to assess the impact of these uses of energy and materials and releases into the environment and to evaluate and implement environmental improvement opportunities. The assessment includes the entire lifecycle of the product (...), including extraction and processing of raw materials, manufacture, transport, distribution, use, reuse, recycling and final disposal" (SETAC, 1993).

The first LCA studies were undertaken in the late sixties and covered some aspects of the life cycle of materials and products, to highlight issues such as energy efficiency, consumption of raw materials and waste disposal. Starting from these early experiences, there has been a gradual spread of use of such means, promoted by the positive results that first applications produced. Simultaneously, however, there were obvious limits to this methodology due, mainly, to the non-comparability of results, owing to the development with different approaches and methodologies [Baldo, 2000]. To fill this gap, in the 1990s, efforts were made by standardisation bodies at national and international levels, aiming to rationalize and harmonize the references in this field.

The development of LCA methodology culminated in the codification of a family of standards, ISO 14040 (Environmental Management - Life cycle assessment), published in 1997. Today the ISO 14040 constitutes the most important reference for the dissemination of these methodologies. The provision recognizes the LCA tool utility in identifying opportunities for improving the environmental aspects of product in the various stages of the lifecycle, in identifying the most appropriate indicators for measuring the environmental performance, guiding the design of new products/processes in order to minimise its environmental impact and strategic planning in support of businesses and policy maker (ISO, 1996). In this logic, LCA is also used as the basis of scientific information communication strategies of organisations, that is, in the definition of instruments that can

be used for this purpose, such as those assertions of type II (environmental product declarations) or of type I (eco-labelling programmes). The European ecolabel, for example, utilises LCA for processing of ecological criteria and environmental product statements are to be assured by the results of a life cycle analysis, according to the specifications in ISO 14025.

There exists a wealth of data and methods for LCA throughout the world today, with government bodies and international organisations recognising that there is an increasing need for guidance on what to use. The UNEP/SETAC Life Cycle Initiative is an example of one of the international activities underway to disseminate life cycle approaches throughout the world, with a focus on developing countries (UNEP 2002). The life cycle initiative and other related life cycle activities, such as the International Reference Life Cycle Data System (ILCD) (European Commission 2008) are instrumental in expanding LCA approaches and in supporting the increasing understanding and application of life cycle assessments. In this way, the expansion of LCA is an approach based on expanding the usefulness of LCA whilst not increasing the complexity of the LCA, thereby decreasing its value.

According to ISO, LCA is a technique for assessing the environmental aspects and potential impacts throughout the life cycle of a product or process or service, which is divided into four phases (see the figure 2):

1. Setting the goals and boundaries of the system (goal and scope definition - ISO 14041)
2. Data collection (inventory analysis - ISO 14041);
3. Environmental impact assessment (impact assessment - ISO 14042);
4. Interpretation of results and improvement (improvement analysis - ISO 14043).

The 4 phases of LCA should not be seen as a fixed sequence or standard of methodological steps, but rather as a cycle of iterations, with frequent changes and revisions of the contents of each, as each phase is interdependent with others.

1) The first stage indicates clearly and coherently the planned application, the reasons why the LCA is developed, the intended use of the results and the intended audience of the study. In particular, in defining the scope of the study, certain elements must be clearly

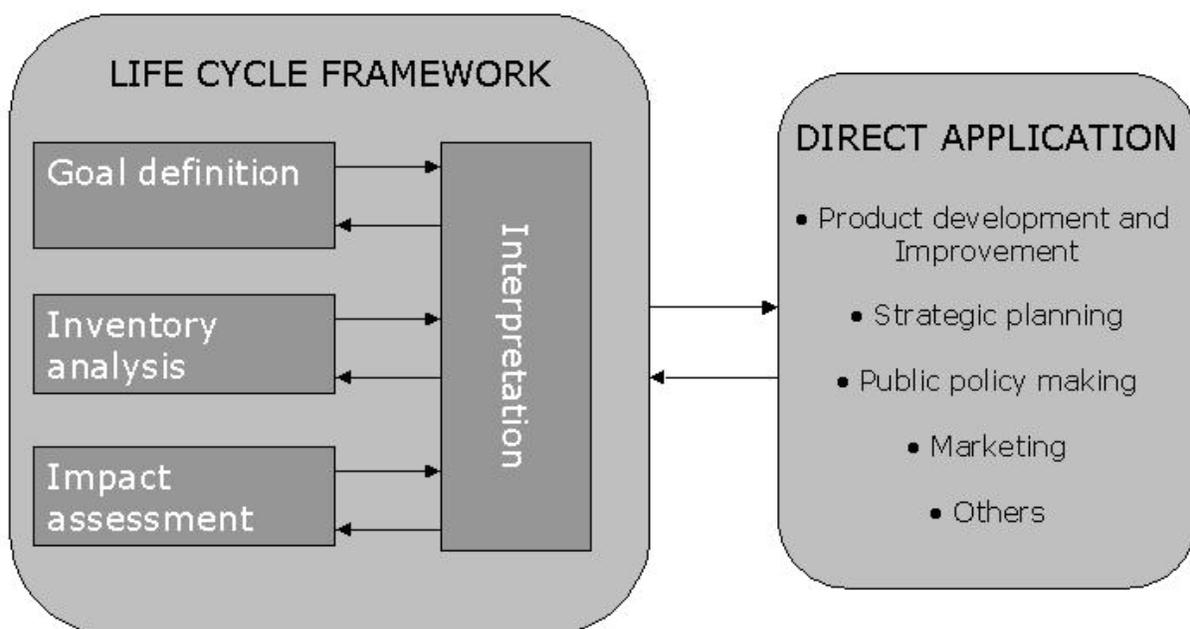


Fig. 2. The phases of LCA

described and taken into account, including: the functions of the product system (or systems product in the case of comparative studies, as LCA can be used to compare the alternative products or processes); the functional unit; the system of the product (defined in the standard as "the set of elementary units of the combined process with regard to the matter and energy, pursuing one or more defined function"); the types of impacts, methodologies for evaluating the impact and the subsequent interpretation to be used; the quality requirements of initial data, etc.

Within this phase, a fundamental step is the definition of the functional unit, whose purpose is to provide a reference in which to bind the inflows and outflows (defined as inflows of matter or energy that enters a process unit consisting of raw materials or products, and outflow matter or energy that leaves a unit process, formed from raw materials, intermediate products, products, emissions or waste), as we assume that the measures and evaluations are conducted according to the provision of the system under consideration. In other words, the system covered by the study is the product, defined not so much by its physical characteristics, as in its function, i.e. in the service that it provides (European Environmental Agency, 1998). If the function performed by the painting of a steel artifact, for example, is the protection of atmospheric corrosion, the functional unit could be defined as the unit of area protected to a predetermined period of time.

Another key step in conducting a LCA study is the definition of borders of the system studied, namely the identification of individual operations (units) that make up the process and their inputs and outputs, which must be included in the study. All transactions, or "process units", within the confines of the system are interrelated: they receive their input from the unit "upstream" while their output constitutes the inputs of "downstream" units, according to the outline of the process studied.

The criteria used to define the boundaries must always be identified and justified in order to clearly spell out the scope of the study.

2) The successive step in the undertaking of LCA's is the lifecycle inventory phase (LCI). This phase involves collecting data and calculation procedures that enable the quantification of the types of interaction that the system has with the environment; these interactions may cover the use of resources and emissions in the air, the releases into water or soil associated with the system-product (Frankl, Rubik, 2000). The process of how to conduct an analysis is iterative in nature: inventory or data collection allows an increased level of knowledge of the system and, consequently, new data requirements may emerge or new requirements or limitations concerning data already collected may be identified. All this may entail a change to collection procedures and methodologies for calculation, in order to maintain a study coherent with objectives and allow, then, the achievement of a consistent audit. A review of the purpose or scope of the study may also be demanded by the emergence of problems related to the non-availability of required information. In relation to the latter issue, it should be noted that recent years have been characterised by a strong development of commercial and public databases both in the private and public domain. National or regional databases, which evolved from publicly funded projects, provide inventory data on a variety of products and basic services that are needed in every LCA, such as raw materials, electricity generation, transport processes, and waste services as well as sometimes complex products (Finnveden et al. 2009). In the private sector, as understanding grew of the increasing importance that the LCA tool has in environmental strategies of enterprises, and in public sector entities, in order to support enterprises in its application. This development

of databases started a process of elaboration which today is available for companies interested in experimenting with LCA methodology on its processes/products. With regard to Europe, it is appropriate to highlight the efforts made by Joint Research Center (JCR) of the European Commission in the development of a database "network", the international lifecycle database, and a relative Handbook (manual), with the objective of making data available to the user via web information from databases from diverse sectors, collected in the field. The UNEP/SETAC Life Cycle Initiative along with the ILCD are focusing on addressing inventory data, among other issues, by building on the currently existing achievements and approaches in increasing consistency and quality assurance. Both UNEP and the European Commission have recognised these tools as an opportunity to spread the LCA methodology to all Community companies, providing technical and scientific reliability and data quality.

The data collected during the inventory phase relates to natural resources and energy use, emissions into the atmosphere and bodies of water, in addition to solid waste. These resource inputs consumed and output of emissions into the environment are attributable to all operations included in the life cycle of the product being investigated.

Clearly, the quality of the data collected with a view to the completion of the inventory strongly determines the significance of the findings of the study. In LCA studies, therefore, it is desirable to use the highest possible percentage of (so-called) specific data – which refer exactly to the system in question or to one "technologically equivalent" (i.e. with sources of energy, raw materials, process phases and similar structures). A strength of inventories carried out within the LCA is represented, in particular, by the methodology of measuring energy consumption that calculates not only the share of energy directly consumed at every stage of the production system, but also the indirect share of energy needed to produce fuels and electricity that normally feed industrial processes and whose values vary from country to country depending on the level of efficiency associated with different modes of production and transformation of energy. Table 1 shows what can be the differences between national energy mix of various Nations.

Nation	Hydro	Nuclear	Fossil fuels and waste	Other renewable sources
Austria	67.6	-	29.2	3.22
France	17.11	75.6	6.49	0,72
Germany	5.28	25.51	61.95	7.26
Japan	9.81	24.91	64.86	0.42
Italy	18.07	-	79.21	2.72
Norway	98.71	-	0.84	0.45
Spain	9.99	15.61	64.4	10
Switzerland	68.17	28.04	3,76	0.03
UK	1,71	17,22	79,4	1,67
USA	7.26	19.11	72.6	1.03

Source: (International Energy Agency, 2007)

Table 1. Mix % of primary combustible sources used to generate electric energy in various countries

These differences lead to consequences for the calculation of the energy consumption of a "product" that systems using LCA techniques can measure. Because a production process can generate, along with the core product, different co-products or by-products, the need arises to define rules to assign each a share of output production, and consumption impacts associated with transactions underway. Such allocation criteria, defined as allocation methods, can be traced back to two main groupings, as follows:

- allocation on the basis of physical magnitudes: is the proportional distribution of environmental burdens on the basis of a physical parameter, such as mass, volume, energy, etc;
- economic allocation: consisting of the distribution of environmental burdens in proportion to the economic value of co-products or by-products. This method, which is not based on any physical parameter, can be applied however only in cases where the physical allocation is not easily applicable.

3) The inventory phase follows that of the impact assessment lifecycle during which environmental effects generated by the system under study are analysed. In other words, this phase is intended to assess the potential environmental impacts caused by processes, products or activities of the study, using the information gathered in the inventory. Every environmental impact can also be associated with one or more environmental effect and the performer of the study has the choice of the level of detail and the impacts to be assessed, in coherence with the objectives and the scope as defined in the first phase of the study. Environmental effects, on the other hand, can be divided according to the level of action: global, regional or local (Baldo, 2000).

Considering the subjective elements that characterize this phase (which evaluate the categories of environmental effects), it is appropriate to bring clarity and transparency with the assumptions that underlie their choices.

Among the categories of impacts more typically used in this phase of the LCA are the following:

- greenhouse;
- acidification;
- eutrophication;
- stratospheric ozone ducting;
- photochemical smog;
- land.

The ISO 14042 provides for two stages of analysis of impacts, the first, which is required, consists of three sequential tasks:

- selecting categories of impacts to consider and related indicators (acidification  $\Rightarrow$  SO<sub>2</sub>, greenhouse  $\Rightarrow$  CO<sub>2</sub>, eutrophication NO<sub>3</sub>, ozone depletion  $\Rightarrow$  CFC11, etc.);
- assigning inventory results to the selected impact categories (classification);
- calculation of the indicators of each category of impact (e.g. GWP, etc.) (characterization);

The second, optional stage, is divided by:

- comparison between calculated indicators and benchmarks (standardisation);
- determining the importance of individual environmental effects (weighting).

Classification consists of the organizing of inventory values of all emissions, gaseous, liquid and solid, caused directly and indirectly by the operations in question, by associating them to the various categories of impact. The characterization, on the other hand, allows the

determination in quantitative terms of the contribution of individual emissions, calculated using the ratios of characterization of each pollutant found in the scientific literature (e.g. IPCC Intergovernmental Panel on Climate Change; WMO World Meteorological Organisation; etc.).

The optional stages (standardisation and weighting) determine to aggregate the results of the various categories of impact in a single index, e.g. expressed with a score, to assess the environmental impact of the studied system as a whole, these methods, however, display a high level of subjectivity and, therefore, do not enjoy unanimous consensus in the international scientific community.

4) during the last phase of life cycle analysis, interpretive, the results of previous phases are summarized, analyzed, tested and discussed in consideration with the objectives of the study, to reach findings and recommendations to address and improve the environmental performance of the system-product analyzed. This stage has, therefore, the purpose of presenting, clearly and completely, the results of the previous phases, in support of decision-making processes and the planning of improvements. The aims and purposes defined in the initial phase are shaped into actions that are planned following this period of the interpretation of results. On the other hand, this phase may involve a review of some fundamentals of the study (scope, nature and quality of the data collected), taking account of the need to achieve the defined objective.

Whilst LCA does enable a comprehensive assessment and considers attributes or aspects of the natural environment, human health, resources and can inform consumer and policy decisions on environmental issues, decision makers must also take into account other sustainability aspects. In order to provide information for decision makers, it has been argued that there is a growing need to expand the ISO LCA framework for sustainability assessment by considering broader externalities, broader interrelations and different application/user needs with often conflicting requirements (Jeswani *et al.*, 2010).

In this sense the combination of common data and models and the synergies that exist between LCA and LCC offer additional advantages of their combined use (Udo *et al.*, 2004). The main difference that emerges between LCA and LCC is the traditional perspective that guides the use of each methodology. LCC adopts traditional perspectives of the life cycle of their "producer" or "customer." The objective is to minimize the overall costs of a product or investment to optimize the use of economic resources and increase customer satisfaction.

The goal of LCA, instead, is to identify and quantify the environmental burdens related to a product over the life cycle.

There are many purposes and diverse motives for which an LCA study may be undertaken, the main reasons may include:

1. The creation of an information system that supports the system's management, resource consumption, emissions and related environmental effects;
2. The identification of critical points in the production cycle or product life cycle to identify areas for improvement;
3. To compare the environmental burdens associated with alternative products or processes, in the selection of suppliers and choices of integration / vertical disintegration;
4. The orientation of the design of new products / processes, so as to minimize environmental impacts;
5. Provision of scientific support for external communication and consumer information.

#### 4. LCC as a tool for evaluating multiannual investments.

The Logic of Life Cycle Costing can be applied even if the object of analysis is not the product but a long-term investment project. In particular, LCC lends itself well to comparative assessments of complex investments, such as investment in capital equipment or in the building & construction sector.

From this perspective, the National Institute of Standards and Technology has defined LCC as the sum of discounted total costs of the design, implementation, maintenance and end of a project over a given period of time.

According to this definition we can distinguish three fundamental components of cost within the life cycle:

1. Cost responsibility of the work / investment to be undertaken;
2. The period of time within which the costs occur;
3. The discount rate used to discount future costs at time  $t_0$ .

The LCC of alternative projects can therefore be seen as the sum of initial investment (I), the present value of replacement costs (R), energy costs (E), and maintenance costs (M), minus the present value of salvage (S) which can be either the sales value at the end of the period or the residual value.

$$LCC = I + R + E + M - S$$

The first component of LCC is of course the cost. There are different categories of cost that must be considered during the lifetime of a project, ranging from the initial cost of investment to the purchase cost of installation or the costs of building a structure, management costs, costs of maintenance and repair and replacement costs.

The following table shows by way of example the main cost components to consider for each category in the application of LCC methodology in the building industry.

Cost elements that occur throughout the life cycle of the project must be added to the residual value or the net value of the investment after the LCC study period. This value consists of several elements, of both a positive and negative nature. For example, there may be the possibility that parts or components of a particular product/project have a high market demand and can be located at an economically advantageous rate. The negative component concerns issues such as disposal costs of waste resulting from the work. In the case of a production line, these costs vary depending on the presence of hazardous substances or the possibility of disassembly and shipment for the recovery of individual components.

The second element of LCC methodology is the time or the time period within which the costs generated by a project must be considered. In evaluating investments, we can split the analysis time in two phases: the first includes the design and implementation of the project, the second phase concerns the operation and eventual disposal. Usually, in order to simplify the analysis, the entire design, construction and generated costs, are understood as the original time unit.

The last component is represented by the discount rate used for discounting cash flows generated over the time period. The discount rate can be defined as the interest rate that reflects the value of the investor's money over time. Two discount rates can be distinguished: the discount rate and the actual rate. The difference being that the real discount rate considers the effect of changing prices, and thus the purchasing power of money, during the period considered.

Initial cost of Investment	Management costs	Repair and maintenance costs	Substitution costs
Management of construction	Fuel for heating	Heat production plants	Heat production plants
Acquisition of land	Consumption of electric energy	Wastewater collection and water distribution system	Wastewater collection and water distribution system
Site survey	Consumption of water	Property insurance	Property insurance
Design	Wastewater	Windows and external walls	Windows and external walls
Acquisition of primary materials and construction	Management and disposal of waste	Interior finishes (floors, walls etc)	Interior finishes (floors, walls etc)
Facilities and technical equipment	Insurance	Fire protection systems	Fire protection systems
Indirect administrative costs	Renting and housing costs	Lighting system	Lighting system
....	.....	.....	

Table 2. Main cost components

The phase of identification and estimation of cost components is certainly the most critical phase, as it determines the accuracy and validity of the entire analysis. In fact, estimates are made in the initial phase of a project, or when the degree of knowledge of the cost magnitudes may still only be approximate. This can result in failing to achieve the desired objectives, and therefore undertaking an ineffective LCC (or failing to choose an alternative project with lower costs). The main reasons as to why an LCC may represent an ineffective analysis are:

- omission of data;
- lack of a systematic structure analysis;
- misinterpretation of data;
- improper use of analysis and estimation techniques;
- an erroneous view of the values and cost parameters;
- a concentration of incorrect or insignificant events;
- errors in the evaluation of uncertainty;
- errors in job control.

These are the points which should act as central to obtaining the real benefit from the use of LCC methodology.

#### 4.1 The integration of environmental aspects with LCC

The increased sensitivity of the market, its actors, and the various stakeholders to the role it plays in the production system to build a development model that meets the needs of

current and future generations, has created a greater propensity for organizations to practice more sustainable conduct of its activities (Durairaj et al., 2002; Settani, 2006).

This move towards more sustainable conduct could enable organizations themselves to identify opportunities for cost reductions, resulting from more efficient uses of natural resources, with the end result being the reduction of the environmental impact of products and services provided (Norris, 2001).

In order to fully appreciate the benefits, both environmental and economic, that the introduction of appropriate changes in terms of product design, raw materials or processes may have, we need to incorporate business activities and waste disposal activities that are attributable to other actors interested in the life cycle of the system in question (Porter and van der Linde, 1996). In other words, the dissemination of life cycle thinking in business management systems is a prerequisite for the definition and implementation of truly sustainable actions.

In this context it is a clear reference to Life Cycle Management (LCM), that is, as an integrated approach that can assist management in managing the entire lifecycle of products or services to more sustainable patterns of production and consumption.

Life Cycle Management can be defined as a "philosophy", direct planning and administration capable of supporting management through:

1. Initial analysis in understanding the stages of the life cycle of a product or service;
2. Identifying, at each stage, the potential economic, environmental and social risks and opportunities;
3. Establishing pro-active systems in pursuing the opportunities identified and managed, or minimize the risks within LCM operational applications that have been developed (Parker, 2000; Epstein, 1996, Epstein and Roy, 1997; Shapiro, 2001), in which some management accounting tools such as Life Cycle Costing (LCC), have been integrated with systems and analytical environmental management tools, such as Life Cycle Assessment (LCA).

The integration of environmental considerations in a tool for cost management ensures that corporate decision-making is based on a growing awareness of the potential consequences in terms of costs and impacts on the environment and human

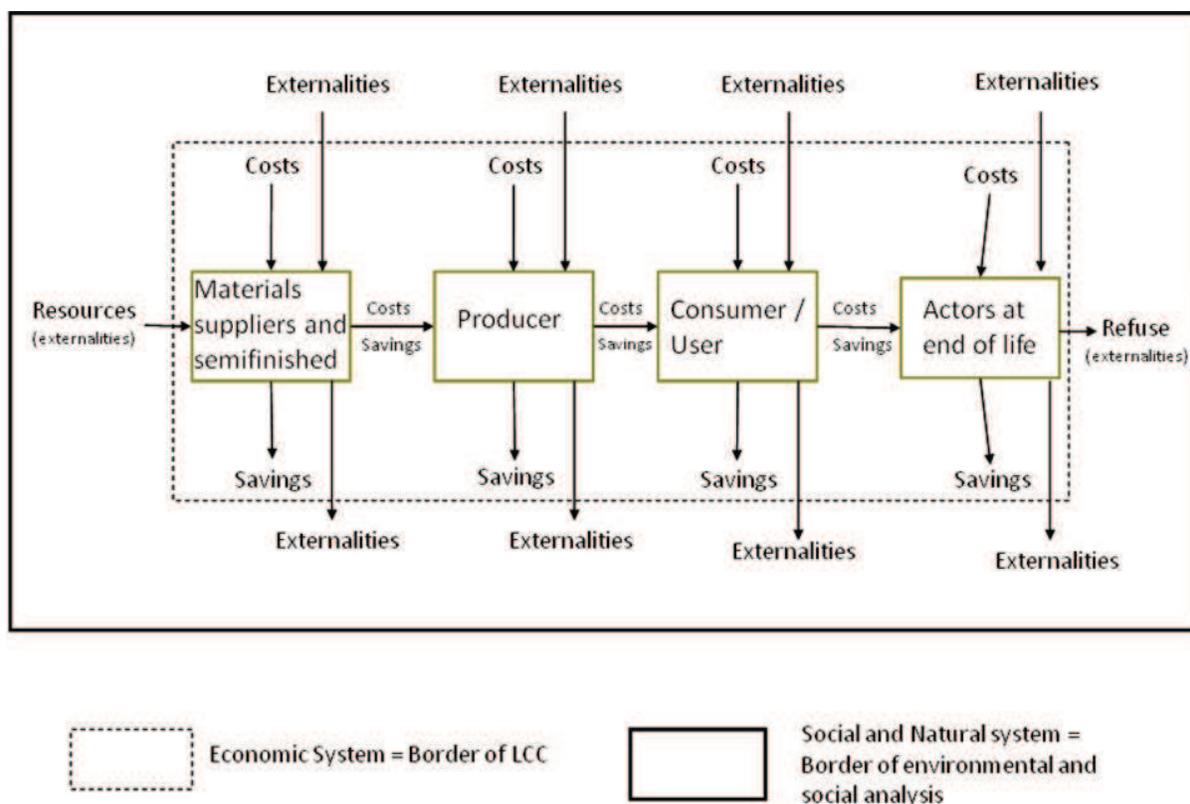
health, which occur in all stages ranging from the extraction of raw materials to waste disposal, and which relate to alternative design and production. Krozer (2008) applied life cycle costing to life cycle management with the assessment of 10 diverse products, based on the assessment of life cycle costs that accommodate demands for emission reductions. The model enabled the assessment of the costs of compliance strategies by available technologies from the past, in comparison with the costs of preventive strategies by innovative solutions in life cycles of products, which could assist companies with compliance in far-reaching emission reductions.

Since a significant proportion of costs and environmental loads are determined - although not yet supported by any of the actors operating along the life cycle - from choices made at the design phase as part of the LCM concept of LCC, it is essential in supporting product development to balance the demands of reducing costs with those of better environmental performance. Thus, the costs and environmental burdens are considered not only within the corporate boundaries, but affect, in a holistic perspective, processes and operators upstream and downstream along the supply chain (Hunkeler and Rebitzer, 2003).

As previously described, Life Cycle Costing (LCC) in its traditional sense is not configured as an instrument of environmental accounting. However, to be usefully employed in LCM as the economic counterpart of an extended type of Life Cycle Assessment, it should be based on systematic analysis, complementary and consistent with the corresponding environmental assessment (Rebitzer and Hunkeler, 2003) - which is usually an LCA-type Life Cycle Costing (LCC LCA-type) (Huppel, 2004). Consequently, we can actually obtain synergies from contextual implementation of LCA and LCC, should the system boundaries, functional unit and key assumptions be aligned between the two methodologies.

Life Cycle Assessment is, therefore, necessarily function-oriented and focuses on a system whose boundaries are wider than those considered in traditional LCC. The key element is the identification of the functional unit intended as a measure of performance of the system under study, which concerns all the environmental burdens (in terms of input and output) resulting from the inventory phase. By function-oriented, we mean that LCC must analyze the processes both upstream and downstream with respect to a given function, regardless of the location or time in which they occur. In the context of LCM, LCC must take into account different economic and environmental demands that characterize the different actors and processes along the supply chain in order to quantify the impact in terms of cost, related to emissions and consumption of natural resources. In this way it could allow for the linking of environmental issues, business strategies and operational processes, considering the costs and environmental impacts that occur beyond organizational boundaries, in relevant stages along the supply chain (Hunkeler and Rebitzer, 2003).

The following figure shows the conceptual framework of Life Cycle Costing, based on the life cycle of the physical product, and the relationship with LCA.



Source: adapted from Rebitzer and Hunkeler 2005

Fig. 3. The conceptual framework of LCC

There is a clear distinction between the economic system considered in LCC, and the natural system considered in LCA, to the exclusion of the external cost or externality from the calculation of the total cost. Traditional LCC considers all costs and revenues attributable to the different actors in the supply chain, while the external costs, which represent the effects of monetized environmental impacts, are not directly charged by individual actors and consequently are outside the economic system.

In an ideal economic system, all externalities, both environmental and social, should be completely covered by the mechanisms of taxation and subsidy, and, therefore, there is no need for systematic analysis on the environmental components, as comprehensive cost analysis along the full life cycle is able to achieve full integration of all three founding aspects of LCM (economic, environmental and social) in a monetary representation.

In order for LCA and LCC to be integrated, it is also necessary that the latter approach is characterized by a static (steady state).

Since the application of the discount rate to future cash flows is intended primarily to take into account uncertainty about the manifestation of the costs themselves (Ciroth, 2003), a probability distribution could be used as an alternative (Emblemsvåg, 2001), or a "scenario analysis" (Hellweg et al., 2003).

Entering the process of costing in LCC, the focus must be on the flows of environmental costs that are generated to produce a single functional unit during its whole life cycle. The range of costs to be considered are very broad, ranging from direct costs to explicit and hidden costs. According to one of the most popular classifications developed by the US-EPA (Environmental Protection Agency), it is possible to distinguish the environmental costs in terms of the ease of measurement and level of integration of the business system of cost evaluation. In addition to the distinction between external costs and internal costs already described above, the EPA distinguishes four categories of costs incurred directly by an organization:

- Conventional costs;
- Potentially hidden costs;
- Contingent costs;
- Image costs.

Conventional costs are those typical of business accounting systems, such as labor costs or the costs of plant and equipment. Although these costs are typically not environmental, the effects can have a significant environmental perspective such as increasing energy efficiency or a reduction of waste processing.

Potentially hidden costs are divided into upfront, regulatory, voluntary and back-end costs. The first are those that occur before a production process and relate, for example, to the design, qualification of suppliers, and analysis of a site. These costs, if they are classified as indirect costs or costs in R & D, can be easily "forgotten" by managers and analysts in the assessments of the costs of system operation. The regulatory concern is the cost necessary for compliance with environmental legislation, such as the cost of sampling and analysis of pollutants, those for waste management, training, insurance, etc. The volunteer costs are those incurred by the organization to go beyond regulatory compliance, for example costs of auditing and qualification of suppliers, implementation of environmental management systems, etc. The back-end costs are costs that are not subject to corporate accounting as they occur at a more or less defined period in the future. They include, for example, operating costs, post-mortem of a landfill or the cost of investigation into a site that is no longer used.

Contingent costs can be defined as quotas for future costs of risk management, or costs in which the event is uncertain. Think of any future legal actions or sanctions that may be imposed on the organization for failure to comply with regulatory requirements. These are costs that must be respected and whose probability of occurrence must be determined.

The image cost is the direct cost of a more difficult environmental determination. The environmental value of the image of an organization may include the value of corporate welfare, reduction of regulatory pressure, customer loyalty, and while the cost report may cover the loss of customers and suppliers as a result of environmental performance, it is not an excellent measure.

The costs of conventional and hidden costs can potentially be determined by the accounting process of Activity-based Environmental Cost Assignment: once the environmental activities within the corporate boundaries have been identified, direct and indirect costs will be allocated according to a criterion of causality, measured by the resource drivers, and a differential approach, in this way working on a reclassification to arrive at the same destination (for example, distinguishing between costs of prevention, monitoring costs, costs of internal accountability and external liability costs) (Hansen and Mowen, 2003). With the procedure of Full Environmental Costing, costs associated with quotas in the event of future production processes and their products can also be considered (Krewze and Newell, 1994).

The physical flows of matter and energy measured by an LCA can provide useful information for; the identification of internal costs with environmental implications (EPA, 1995); the drivers most capable of the appropriate allocation of direct costs, associated with flows of matter and energy (Orbach et al., 2003); and processes for allocating these costs to the functional unit chosen for analysis. Furthermore, identification of these flows allows for the construction of complex indices

capable of measuring the environmental load or the impact of a product or service, complementing the information provided by the analysis of environmental costs.

The inclusion of external costs in LCC analysis has several proposed approaches. There are numerous authors who have advanced methodologies for the calculation of external costs (Rebitzer and Hunkeler, 2003, Lazzari and Levizzari, 2000; Shapiro, 2001), but the limitations of these methods are still evident, especially the difficulty calculating estimates of complex monetary phenomena which incorporate the different forms of pollution and their effects.

Some authors propose to consider only the internal environmental costs because domestic representation of environmental load (Borghini and Vicini, 1997), and complementary monetary information determine at least one physical or environmental impact.

#### **4.2 Integrating LCC with social aspects**

While the integration of the economic impact and environmental impact generated by a product over its life cycle is at a fairly advanced stage, the development of life cycle approaches to assess the social impact of a product is still at the embryonic stage.

Reconstruction of the range of social impacts, both positive and negative, on the various stakeholders, relating to the design, implementation and use of a product is a somewhat difficult operation, while the identification of impact categories and aggregation through quantitative indicators seems almost impossible.

Within the scientific debate, we can distinguish different methodological approaches, amongst the most interesting are social life cycle assessment and the social life cycle impact assessment.

The first, developed by Hunkeler (2006), is a proposal to quantify the social impact of a product in which the key element is the total hours worked. The developed methodology

incorporates the basic steps of the LCA and provides a quantitative tool for comparing the social impact of products, offering itself as a complement to Environmental LCAs and LCC for an integrated measure of sustainability.

A distinctive feature is certainly geographical: that in both LCC and LCA, costs or environmental impacts during the life cycle of a product irrespective of the geographical, or rather the connotation, is not as important except for the determination of the energy mix in the country where the project took place.

The societal LCA, and in general all life cycle approaches that seek to take account of social impacts, are site-specific, i.e. the geographical significance is important for calculating key indicators such as those related to health care, housing, or education.

The methodology proposed by Hunkeler includes five main phases:

1. Data collection for each unit process and geographically specific (inventory analysis);
2. Calculation, of each of the major geographic areas, hours worked per unit processes;
3. Calculation of the range of work crossing the inventory data analysis and distribution of unit labour process, and geographical location of points 1 and 2;
4. Estimation of regional characterization factors for each category of social impact;
5. The social LCA result of using the intersection of the data referred to in paragraphs 3 and 4.

The Societal LCA focuses exclusively on one category of stakeholders: employees. As previously anticipated the units are hours worked, a value that lends itself easily to currency conversion. The impacts identified are 4 categories: health care, housing, education and needs (necessities). The characterization factors represent an estimate of hours required in each geographic area to purchase units of each impact category. The entire analysis result indicates the contribution of the functional unit of each purchase of "social need".

Assuming that the social impact can be measured by hundreds of indicators which are difficult to be clustered and have an important local connotation, Hunkeler proposes a "geographically specific" methodology. It is a highly complementary method to both LCA and LCC - in terms of system boundaries of the functional unit - which summarizes the impact of the life cycle in a few quantitative indicators. This element of strength is also the cause of its greatest weakness, in fact, over-simplification of the method has resulted in using the number of hours worked as the sole determinant of 'social', connecting only the wellbeing of people to the wealth generated from their salary.

This differs to the diverse approach used by Dreyer et al. (2006) in outlining the main features that must be incorporated in a Social Life Cycle Impact Assessment. While keeping the basic stages of life cycle assessment, the tool is not intended as an immediately integrated measure with the others to complete the life cycle view of sustainability of a product, but intends to build, using a two-layer system of indicators, a social identity map of the product formed by the sum of individual social profiles of the companies involved in each stage of the life cycle. These profiles are characterized by social effects generated on three main stakeholders (employees, local community and society), from activities to develop the product. Hours worked are determined via a share factor methodology, with the total combined hours worked by each actor to produce a functional unit.

Unlike societal LCA, in this method the hours worked are used exclusively as a weighting factor, and impact indicators are more complex and heterogeneous, being of both a qualitative and quantitative nature, aiming to provide a measure of the level of "protection and promotion of human dignity and welfare."

The system of indicators for measuring social impacts are built on international standards like the Universal Declaration on Human Rights and ILO Conventions and Recommendations, and on major national and local regulations. The latter aspect points to the previous approach, such as the geographic component being relevant to an analysis of the social impact of a good or a service.

However, the complete definition of the methodology of the Social LCIA is still under development, although some impact categories and indicators have been tested successfully in different organizations. It is therefore necessary for further research and trials to overcome those limitations of using a qualitative approach - which makes the model difficult to integrate with other life cycle tools, whilst avoiding an over-simplification, which would diminish its effectiveness.

#### **4.3 LCC as a measure of eco-efficiency**

To achieve sustainability there is no universal approach, but there exist different methods and concepts that can be used to guide society toward more sustainable patterns of production and consumption. One of these is certainly the concept of eco-efficiency, which combines two of the three pillars of sustainability: the economic and environmental. As defined by the World Business Council for Sustainable Development (2004) eco-efficiency is achieved through the provision of goods and services at a competitive price that satisfies human needs by increasing the quality of life, and progressively reducing ecological impacts of the use of resources throughout their entire life cycle at a rate in line with the estimated capacity of the Earth. It has been argued that for eco-efficiency measures to be calculated, and to add corporate value, it is essential that conventional accounting and financial management applications are integrate with natural science (physical) measures (Schaltegger et al., 2000).

The WBCSD has identified seven elements that an organization can use to increase their eco-efficiency: a reduction in the use of materials and energy, a reduced dispersion of toxic substances, an increased use of recyclable materials, maximising the use of renewable energy, the extension of product durability and increasing the intensity of services.

Acquiring information on eco-efficiency of a product or process not only provides useful information to management regarding the company's performance, but may be subject to communication processes aimed at strengthening dialogue with stakeholders, which can potentially improve a company or products' image. De Simone and Popp (2000), have classified the possible benefits of eco-efficiency into five categories:

- Reduced operating costs due to poor environmental performance (eg. Electricity consumption);
- Possible reduction in future costs due to poor environmental performance (eg. Legal penalties or lost profits related to forced interruption of production);
- Reducing costs of financial capital;
- Increased market share and improving market opportunities;
- Strengthening brand and corporate image.

Measuring eco-efficiency is based on the construction of indicators capable of linking economic and environmental components. There are numerous methods for calculating the basis of components chosen for the construction of the indicator. Since eco-efficiency concepts go beyond corporate boundaries, we require the use of data that is representative of the entire life cycle.

The method developed for the definition of the key interpretation for the Environmental Product Declaration (EPD) Steen et al. (2004) used Life Cycle Costing to build an index capable of measuring the eco-efficiency of a product throughout the entire life cycle.

$$\text{Eco-efficiency} = 1 - (\text{EDC} / \text{LCC})$$

The index constructed by the authors is the ratio between the costs of environmental damage (Environmental Damage cost EDC) and the total cost of the product throughout the entire life cycle, and is expressed as a percentage value (the value 100% indicates, for example, that a product does not produce harmful impacts on the environment).

The EDC is a monetary measure of environmental load units (ELU Environmental Load Unit) generated from the production of a product with respect to impact categories similar to those used in LCA studies: emissions of greenhouse gases, acidifying gases, disrupting ozone gases, photochemical smog precursors, non-renewable energy resource consumption and emissions of substances that contribute to inadequate oxygen amounts in water.

One study by the CPM (Centre for the Environmental Assessment of Products and Material System) has verified the validity and enforceability of the index as a measure of eco-efficiency by comparing two versions of the electric motor HXR500, with or without the ACS800 frequency converter, produced by the Swiss-Swedish multinational ABB (Lyrstedt, 2005).

The measure of the eco-efficiency index showed that the combination of the electric motor with the converter ACS800 enhances the economic value of the asset while reducing its environmental impact.

	<b>Scenario 1</b> (HXR500)	<b>Scenario 2</b> (HXR500 e ACS800)
<i>Life Cycle Costs</i>	40501 sek	21615 sek
<i>Environmental Damage Costs</i>	7800 sek	3922 sek
<b><i>Eco-efficiency Index</i></b>	<b>81%</b>	<b>82%</b>

Table 3. Eco-efficiency measure of the ACS800 Converter

## 5. Conclusions

The overview given in this chapter has shown how life cycle costing is a very flexible tool that supports the various actors in the economic arena in the new challenge of sustainability. The capacity of life cycle costing to estimate environmental burdens in financial values, by integrating economic and environmental information of physical evidence, has been largely demonstrated, however, some doubts and uncertainties remain concerning the approach to be used.

Furthermore, recent contributions from the literature on the integration of social impact studies on the life cycle of a product demonstrate there is much room for development. While we are still in the early stages on the side of methodological approaches, it is desirable that in the future there be more trials in order to find a perfect blend between simplification and efficiency.

The social component in the life cycle approach is certainly the most complex element in working towards a tool capable of integrating the three elements of sustainable development. Connecting elements should be sought with other lines of research that have potential synergies. For example, the theme of intangible assets and measures of corporate social capital could be a possible area of development with a view to analysing the contribution of intangible resources of the entire lifecycle of a product.

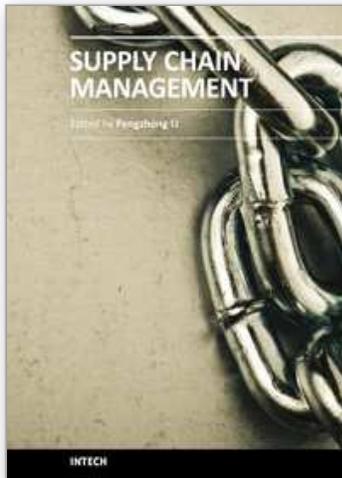
The use of LCC as a tool-oriented sustainability approach should be analysed also in terms of communication to the consumer. The growing sensitivity of the buyer, be it professional or personal, highlights that market demand is growing for clear information about environmental and social impacts related to a product or service. The perspective could be that LCC provides a condensed function that is able to actually make consumers aware of the sustainability of their choices, economically, environmentally and socially.

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The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.

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