# Product Design and Life Cycle Assessment

Ireneusz Zbicinski, John Stavenuiter
Barbara Kozlowska and Hennie van de Coevering

Book 3 in a series on Environmental Management

The Baltic University

Environmental Management

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1. Environmental Policy – Legal and Economic Instruments

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# Summary of Contents

# Contents

# Preface

The main goal to elaborate this book was to deliver a profound description of environmental aspects of product design, which is one of the most important issues of Environmental Management Systems. Product Design is sub-divided into several areas like, ecodesign, life cycle assessment, LCA, and product-related environmental policies.

The Ecodesign part of the book introduces the principles of ecodesign taking into account the need to develop products, processes and services so that they cause minimum ecological impact and environmental damage throughout their lifetimes.

However, the heart of the book is LCA. As compared to other LCA books we paid more attention to practical applications, and particularly how to assess the environmental impact and how to run your own LCA analysis. We described thoroughly the role of LCA in the EMS domain showing that LCA is only one of many techniques and methods applied in effective environmental management, which can support goal setting, policy determination and planning of management activities. We also presented LCA analysis of systems and information management.

The Ecodesign and LCA part of the book are supported by video material, case studies and software, which enables the students to run the LCA cases. There is an introductory video of 10 minutes on an accompanying CD, *Ecodesign – A Promising Approach* to give students a general overview what EcoDesign concerns. Another video on the CD, *Finding the Right Track: Environmental LCA in the Industry* (12 min.) is prepared as an introduction to the LCA course.

Several thoroughly described examples presented in the book should encourage and help users to make their own LCA analysis of a service or product. The case studies are developed to achieve theoretical and practical experience in running LCA. The case studies have been carried out in real projects. The cases can be used as an introduction to get more insight into the gained knowledge by the reader. In the LCA part, several comprehensive case studies are available: a case study on wind turbine, plastic and PVC frame windows and MIPS of passenger car and municipal bus analysis which can be carried out with the support of Excel sheets provided on the CD. Interesting and creative LCA classes might be run using Economic Input-Output Life Cycle Assessment designed for simple and quick LCA instead of conducting the detailed analysis recommended by the ISO standards, which requires considerable attention, time and experience. All data necessary to make inventory analyses for the case studies, and detailed descriptions how to use Excel sheets and demo versions of SimaPro for LCA, are provided in the book.

Academic teachers from several disciplines and expert teams from local and national departments were involved in handling this interdisciplinary material. The LCA part of the book was elaborated mainly by three authors; Ireneusz Zbicinski, John Staveniter and Emilia Kowalska. Barabara Kozlowska and Hennie van de Coevering wrote about the aspects of ecodesign and environmental policies in the book. Joachim Spangenberg delivered a most thoughtful introduction to the book.

We would like to express our appreciation for the help of Prof. Lars Ryden with his invaluable essential comments and edition, which gave the book its final shape.

Many thanks go to Donald MacQueen and Nicky Tucker for professional comments and assistance.

We hope that users like students, designers, etc. after reading this book will gather a good insight into the whole process and involvement in product design.

*Lodz, April 2006*
*Ireneusz Zbicinski*

# INTRODUCTION
# Society and its Products

## The Artefacts of Societies

The history of humankind can be read as a history of her products – and vice versa. Our knowledge of earlier societies is based not on an understanding of their tradition and culture, but on analysing their artefacts, or, more precisely, the waste they left behind. Without arrowheads, bones or potsherds we would know little about their lives. Our way of interpreting human history is to a large degree an anthropology of products and their waste.

Waste is the *Ianus face* of products and production, its undesired but unavoidable backside. Its sheer volume developed into a key determinant of urban planning already in ancient Rome, was the breeding ground for the plague that killed a third of the European population in the 14th to 17th century, and accelerated its growth with the emerging industrial revolution. Industrialisation was only possible based on new infrastructure, production facilities, roads and railways, their production and maintenance, and finally, the disposal of waste produced in this process. The growth of waste heaps would have been the most telling symbol of the new era, even more so than the smoking chimneys [Spangenberg, 1994]. The pattern of production and consumption, which emerged and in its basic traits remained unchanged right into the 21st century (Figure 3), is a wasteful one: more than half of all materials activated never enter the production chain. Vance Packard was right to call our societies "wasteful societies" [Packard, 1960]: as products become waste after use, as product life is decreasing and as recycling covers less than 2% of all materials activated, the production process is essentially a "wastisation" process of labour and resources.

For instance, while the total volume of resources needed to provide a vacuum cleaner for households is several hundred kilograms, its total time of service delivery (i.e. the use time accumulated over its lifetime) is about two weeks, and for an electric drill it is less than two days [Striewski, 2003]. An average German car is produced by turning about 10 tons of resources into 1 ton of a technical artefact used to transport on average 100 kg of humans. This service (enhanced mobility, used mainly in cities where the average car transport velocity is ca. 15 km/h, well below the 17-20 km/h of the horse carriage, and for distances of less than 1 km, where it would have been faster to walk on foot) is enjoyed for about three months (average use in Germany 33 minutes per day over 12 years, making the car an "auto*stabile*" rather than an "auto*mobile*"), and then the car is thrown away; recycling of spare parts plays no significant role

> ***"The production process is essentially a 'wastisation' process of labour and resources."***

**Figure 1. Archaeological site.** *Our understanding of earlier civilisations is based on the products, or rather waste, they left behind. Photo: Armin Schmidt, University of Bradford.*

so far [Spangenberg, 2004]. The relation of resource consumption to the volume of services generated is rather absurd.

Whereas products as such had been with human development since its first day (for a long time, using instruments had even been considered a key criterion to distinguish between humans and animals), with industrialisation a new mode of production took over. Products were no longer manufactured by handicraft workers in the neighbourhood and exchanged for farmers' goods. Instead major facilities produced a high volume of more and more specialised products on their assembly lines, based on Taylorism, the disintegration of production processes in small repetitive steps to increase productivity. The products were traded on an increasingly globalised market – at the end of the 19th century, trade volumes (relative to production size) and economic integration were as high as in the early 21st. Traditional goods were now produced industrially, i.e. standardised, in large quantities, and at low prices. New products were invented, and increasingly the satisfaction of all kinds of human needs was commodified.

Mass production, however, faced one serious challenge: who would buy the products? It was Henry Ford who decided to pay a decent wage to his workers so that they could afford the products they were producing. Fordism is the basis of mass consumption, and the traditional cornerstone of our social models: whenever mass income declines, the result is almost inevitably a decline in consumption, production, employment and tax revenue. With this in mind, the simultaneous occurrence of discourses about European societies being consumer societies and about the end of Fordism and the post-Fordist society are rather remarkable.


**Figure 2. Waste dump.** *Production-consumption in Europe today is essentially a linear flow from resources to waste; only some 2% of products are recycled. 98% ends in incineration and on ever growing land fills, the most telling symbol of industrial society. Photo: European Communities © 2005.*

## Production and Consumption Today

Every process of production and consumption begins with an intellectual act: recognising the use potential embodied in a part of nature and landscape, be it land for grazing, wood for construction or ores for mining. In the next step, a value is attributed to what is now no longer perceived as a part of nature but a resource (although physically probably nothing has changed so far: the perception counts). This attribution of a value refers to the potential market value of the resource, i.e. the demand that people other than the owners have, not to any kind of intrinsic value [Altvater, 1985]. The resource is exploited if this market value is higher than the cost of exploring and exploiting the resource, which in reality is the cost of waste production: overburden, drainage water, waste heaps are all parts of nature which have been in the way of commercial exploitation of a resource (if the resource had been defined otherwise, what is now the waste might have been part of valuable product, and vice versa). So every production process necessarily begins with waste generation, and with negative environmental impacts.

In a Western European economy, 50-60 distinct abiotic materials, including energy carriers and water, but not air, that have been defined as such resources, are extracted from nature and crossing the border into the economic sphere at about 20,000 points of entry (German data, with one oil or gas field considered to be one point of entry) [Spangenberg et al., 1999]. There they undergo mechanical, thermal and (bio-) chemical treatment to be transformed into products, production waste and liquid or gaseous effluents. A majority of all materials is thus transformed into waste, while a minority becomes products which, after their use time and perhaps a round of recycling, become waste as well [Spangenberg et al., 1999]. In physical volume, the goods and services we consume are a mere by-product, albeit a desired one, and the main product of our productive processes is waste.

The production process increases the number of substances dramatically: in Europe, on the output side about 100,000 substances (about 33,000 of them in significant quantities) and

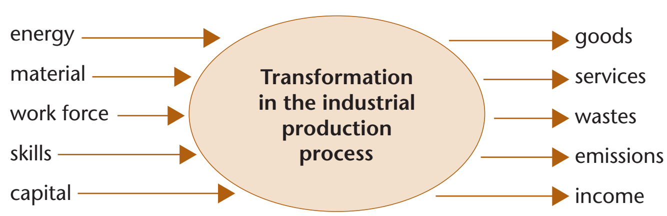


**Figure 3. The industrial transformation system.** *The pattern of production and consumption, which emerged in early industrialisation has remained unchanged into our times.*

2 million products leave the human sphere and are returned to the environment [Sturm, 2001], at countless points of exit (smokestacks, drainpipes, waste dumps, exhaust pipes,…). 30,000 or 90% of the mass-produced substances are so-called “old substances”, which have not undergone a state of the art environmental assessment as they were marketed before appropriate chemicals regulations came into force (on the EU level, in 1981). Although all of these old substances should have been assessed for their health and environment impacts, starting with a group of 140 “hot candidates”, 20 years later only 20 of them had been fully scrutinised. The delays are caused by the complexity of tests required as much as by the reluctance of the chemical industry to provide the necessary data [Wille, 2003]. The latest initiative of the European Commission (the REACH Directive) suggests registering all old substances (i.e. to collect meaningful data for them) by 2012 and to assess their impacts based on these data by 2020 – an undertaking seen as “overly ambitious” by the business lobby. This is a quite scandalous delay in consumer protection, meaning that even the some 1350 carcinogenic and mutagenic (i.e. cancer causing and genome damaging) substances and the about 150 bio-accumulative ones will be on the market at least for another half generation. Obviously, the sheer numbers of substances to be controlled and their emission points are beyond the scope of effective control. As long as we do not manage to design our products so as to minimise the consumption of resources and limit the damage potentials created in the transformation process from the very beginning, only limited progress towards environmentally benign production and consumption will be possible. This is why the attitude of designers, architects and producers is so important for sustainable consumption.

Nonetheless substituting at least substances with proven harmless characteristics for these suspicious ones in product design would be a significant step forward. However, so far the portion of such “eco-products” like solvent-free colours or recyclable packaging material has only a minor share in the total production of the chemical industry. Consumer pressure on retailers and consumption good providers could accelerate the substitution process by upstream pressure on the producers, but a key condition for this is the willingness, as well as the knowledge, of the consumers, and the readiness of the production sector, to offer suitable alternatives.

***“The consumption of primary energy, total material flows and land use intensity can thus be considered a reliable proxy measure for total environmental stresses.”***

## Quantity Counts: the Output Side

Not only the quality of certain substances causes environmental concerns, the sheer volume of resource consumption is a reason to worry. Most current environmental problems are closely linked to the consumption of energy, material flows and land use intensity. As a matter of fact, except for the impacts of small amounts of highly bio-active substances, and of spatial effects (e.g. ecosystem fragmentation by infrastructure

**Figure 4. The input output analysis of the material flow.** *Resources flow into the society as some 60 different substances, in a country like Germany at about 20,000 entry points, while they leave society as about 2 million different products, containing about 100,000 substances, in countless points. It is obviously easier to control the input, than the output side. Still today’s environmental policy and management focus on the output, as emissions control, product control, chemicals management, and waste management.*
*Photo 4a: © 2005-2006 morguefiles.com Photo 4b: Redundant Technology, www.lowtech.org*

construction), the most relevant environmental problems in Europe can be traced back to the over consumption of these basic resources [Spangenberg and Lorek, 2002]. The consumption of primary energy, total material flows and land use intensity can thus be considered a reliable proxy measure for total environmental stresses.

The volume of resources activated for maintaining service flows from stocks as well as from consumer goods, i.e. the total physical throughput of the economy [Daly, 1991], can be assessed in different ways. Any meaningful assessment of human-made environmental distortions, diverse as they are in their nature as well as in their causes and origins, must be based on a life-cycle wide approach, from resource mining to final disposal. However, depending on the kind of problem to be dealt with, and on data available, different kinds of flows and different system boundaries are selected (Figure 5).

*DPO: Domestic Processed Output* covers the classical way of describing the interaction of effluents from the production and consumption system and the biosphere. It includes all those substance flows from domestic activities which regularly show up in environmental statistics. Besides the recoverable products, the flows to be taken into account include [Schmidt-Bleek, 1994] along the chain of production, consumption and disposal:

- The use of substances which are deliberately dissipated in the environment for a specific purpose, e.g. pesticides or fertilisers in agriculture or salt on icy roads in winter time.
- Emissions and deposition of solid, fluid and gaseous wastes, released into the environment as a result or side-effects of human activities like $CO_2$ from the energy consumption during manufacturing and use of a product.

In some respect, the resulting pollution pattern from effluents and waste mimics the consumption patterns: the global consumer society leaves its footsteps in every corner of the World, from DDT in penguin eggs to dioxins for breast-fed babies and – a more subtle, but nonetheless effective kind of pollution – endocrine disruptors, pseudo-hormones changing the regulatory processes of organisms including humans.

*TDO: Total Domestic Output* adds the domestic hidden flows to the DPO. They comprise all those physical flows, like overburden or strip water from mining, which, due to their lack

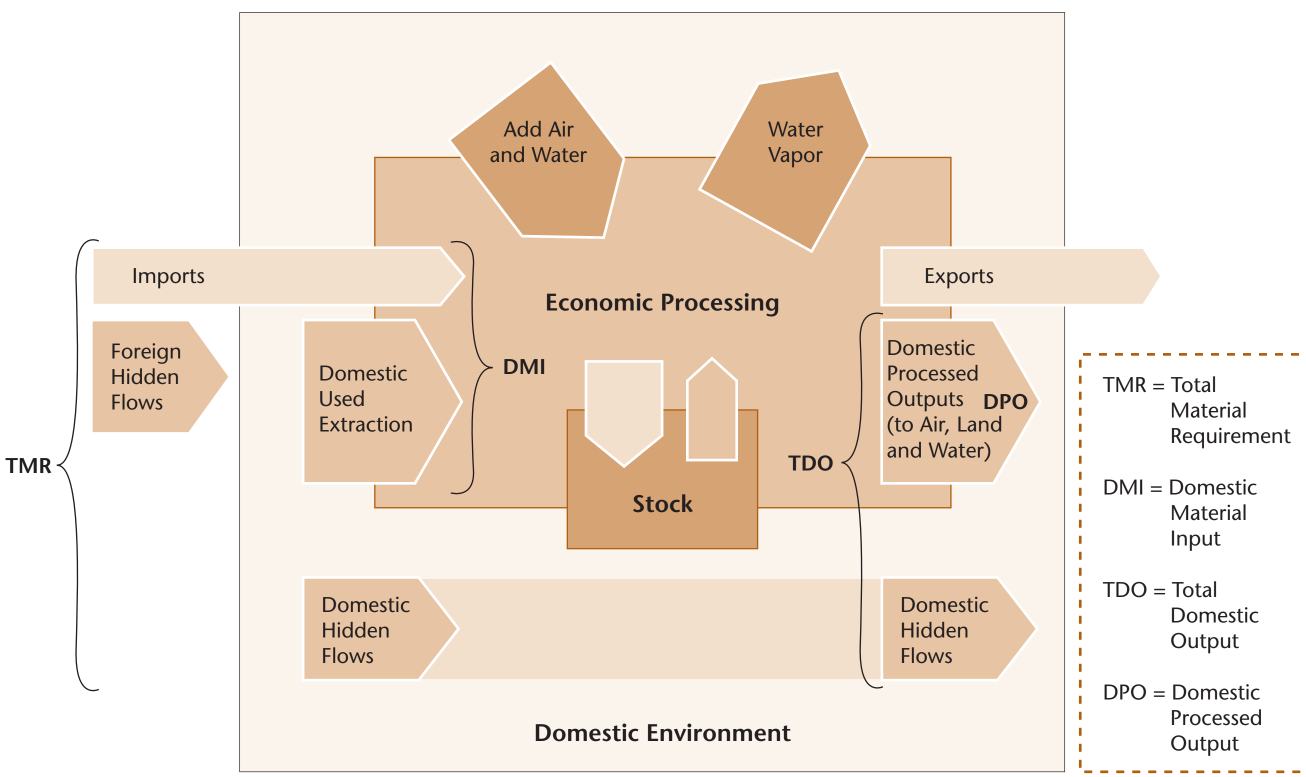


**Figure 5. Economy wide material flows**. *The material flows in society are accounted for in four different ways. The TMR (Total Material Requirement) consists of the DMI (Domestic Material Input) and the hidden flows, domestic and foreign. The TDO (Total Domestic Output) consists of the DPO (Domestic Processed Output) and the domestic hidden flows. The processing of resources in society (Economic Processing) provides material that stays in society, e.g. as infrastructure, of durable goods, or is used in consumer products, and in the emissions associated with both [Bringezu and Schütz, 2001].*

of economic value, are most frequently not accounted for in the production statistics, and those materials that have not entered the production process at all. These materials are usually characterised by a negative economic value, i.e. the cost of waste disposal, and are most frequently not even taken into account in waste statistics [Striewski, 2003]. Once they are put to productive use like residual biomass from food and wood production, they show up in the production statistics. Environmentally they represent open bills, irrespective of their economic valuation, causing environmental impacts like acid rain, ground water contamination and a variety of not yet known unspecified damages, which we will have to deal with in future. Some of these effects are more or less stationary like heavy metal pollution in the ground or in sediments, while others spread ubiquitously. Domestic output accounting is the basis for some more recent policy instruments like waste taxes and levies.

## Matter Matters: the Input Side

*DMI: Domestic Material Input* accounts for those kinds of physical inputs into the economy which have been extracted domestically, plus the volume of imported goods (both without the hidden flows associated with them, and imports without the production waste generated in the country of origin). As has been mentioned, the number of gates between ecosphere and troposphere, and the diversity of substances are much lower on the input side, and accounting for inputs covers the immediate outputs as well as those realised later due to a period of staying in the stocks. Therefore input accounting provides a more comprehensive assessment of the environmental damages caused by today's activities, and offers itself to innovative instruments for reducing the total throughput, as energy taxation or the Swedish tax on gravel [Palm, 2002].

For Denmark for instance, as a highly trade dependent country, the DMI in 1997 has been about 185 mln tonnes or 35 t/cap. Allocated to final demand, resources have been used as shown in Table 1. However, these figures do not reflect the full picture of the Danish footprint on the global environment: as the DMI does not take the imports into account, the goods and services purchased by the revenues from the exports do not show up in the statistics. Once included (i.e. when calculating the TMR, see below) Denmark falls quite in line with its neighbours, and the relevance of the contribution from exports is greatly diminished. Nonetheless the table very clearly indicates the importance of the physical dimension of international trade, in addition to the monetary one [Döppe et al., 2003], and the matter-money dichotomy of all economic activities.

*TMR: Total Material Requirement* is the all-encompassing measure including the domestic material input plus the hidden flows, both domestically and in the country of origin. As compared to the DMI it covers not only the domestic impacts of economic activities, but their global environmental consequences.

Naturally, the figures for different measurement methodologies vary considerably. So for instance for Sweden domestic used extraction (DMI minus imports) in 2001 was 20 t/cap, with DMI 25 t/cap and TMR 45 t/cap [Palm, 2002].

The figures vary as well considerably between different countries, due to their level of consumption and to the structure of their domestic industry (for instance, Germany has a high contribution from lignite mining, and the Netherlands a

**Table 1.** *Danish Domestic Material Input (DMI) in million tonnes by final demand 1997 [Pedersen, 2002].*

| Final use | Volume (mln t) | Share in national DMI (%) |
|---|---|---|
| capital formation | 38 | 20 |
| export of goods and services | 94 | 51 |
| government consumption | 10 | 6 |
| private consumption | 42 | 23 |

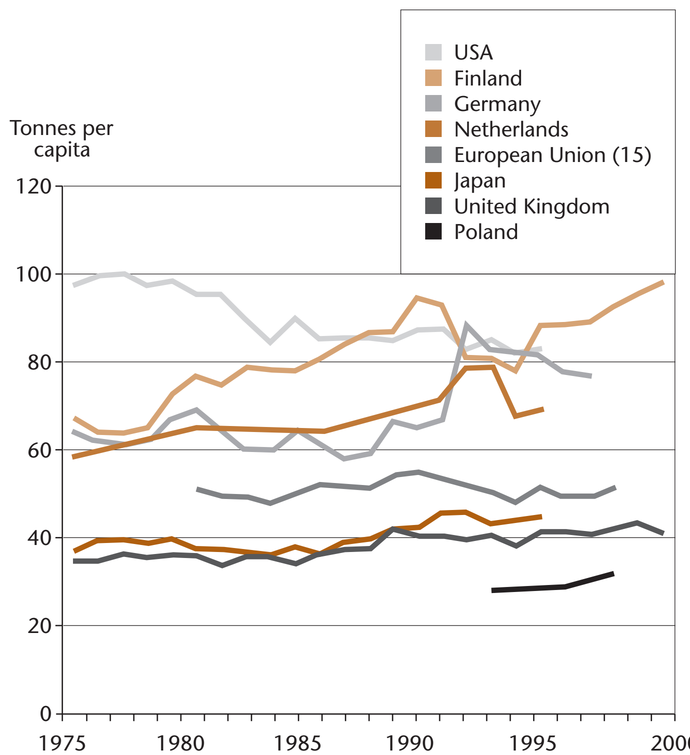


**Figure 6. Total Material Flows in Europe.** *The TMR is given for EU-15 as well as for 7 individual countries between 1975 and 2000 [Bringezu and Schütz, 2001]. For many countries, as for EU-15, it has been stable or decreasing in spite of a growing economy (reported as GDP). We say that economic growth is relatively or absolutely decoupled from material flows [Azar et al., 2002].*

similarly high one from meat production, [Adriaanse et al., 1997]). Both countries have a TMR of about 70 tons of material use per capita per year, with the German TMR gradually returning to its pre-unification level. The lowest level is found for Japan and the UK at about 40 t/cap; Finland has outgrown the USA and now exhibits the highest resource consumption level of about 100 t/cap (Figure 6).

Overall the figure illustrates the trend to a relative, but not absolute delinkage of economic growth and resource consumption (except for the USA): despite a growth of at least 50% in GDP since the mid 1970s, the TMR did not follow suit but remained rather constant (Japan, EU 15, UK) or grew less than GDP. Only the USA experienced an absolute delinkage, i.e. while the economy grew significantly, the TMR decreased in absolute terms, from about 100 tons per capita to about 80 t/cap, a value rather similar to those in some European countries like the Netherlands or Germany. Another exemption is Finland: despite its focus on IT industries, its TMR grew from around 60 t/cap to nearly 100 t/cap, a rapid increase otherwise typical of newly industrialising economies. The Finnish example illustrates that even a modern high-tech business structure cannot exist without underlying traditional and material intensive production, and provides a warning to all those who hope that the ongoing structural change towards a knowledge based economy would in itself guarantee a significant dematerialisation of the industrialised economies.

## Piling Up: the Relevance of Stocks

Although environmentally relevant only when they are disseminated, the materials accumulated in the stocks of society deserve a closer look, too. Stocks are public goods like roads or buildings, private goods like refrigerators, cars and houses, or economic goods like machinery, railway lines and telecommunication infrastructure. Some of the goods are only consumed for a short time before they wear out or become unfashionable (fluctuating markets); others are rather replacements in saturated markets (Table 2).

**Table 2.** *Market types and life expectancy [van der Voet et al. 2002, modified].*

| | Economic life time | |
|---|---|---|
| **Expectancy type of market** | *Short* | *Long* |
| *Fluctuating* | Tamagotchis | Personal computers |
| | Plateau soles | Transformers |
| | DDT | PUR foam |
| | Rubic's cube | Play station |
| *Saturated* | Blue jeans | Washing machines |
| | Newspapers | Water pipes |
| | Phosphorus | Bricks |

On the one hand, their mere maintenance requires an increasing volume of monetary as well as resource expenditures without providing additional welfare: they need to be cleaned, upgraded, repaired or renovated. This creates a positive feedback cycle: as a rule of thumb, the more materials we have fixed in the stocks, the more flows we need to maintain them. On the other hand, the stocks are bound to become waste – like everything else, although after a longer time span, so the substances with rather unknown long-term risks will be with us for quite some time beyond even the 2020 deadline of the EU chemicals policy.

For instance, experts warn that around the middle of the century CFC emissions from construction foams are due that are about as great as the total releases during the last century. Similarly, the decreasing trend of emissions of heavy metals is expected to be reversed soon, due to releases not from production, but from the stocks of products. In order to control emissions in the long run, therefore a stock management is required in many cases [Van der Voet et al., 2002].

## The Driving Forces: Capitalist Production

Industrialised, market-based capitalist societies have embarked on a very specific development path in their pursuit

**Figure 7. Material flows and infrastructure.** *The material flows into society are to an extent adding to technical infrastructure, such as buildings, roads, etc, turned into products, or released as emissions to the environment in connection with production or consumption. However also infrastructure and products leaches to the environment; e.g. PCB leaches from building materials and electric equipment. Photo: European Communities © 2005.*

of happiness: accumulating material artefacts is considered as increasing wealth, and wealth has become synonymous with well-being. Like the production of material goods, knowledge, caring for people, entertainment and nature are turned into commodities, making the access to them wealth-dependent. Reflecting this change, human relationships and the environment are increasingly described in economic terms, as being natural and social "capital" and as providing "services", as products are service-providing man-made capital – capitalism reduces everything to the "cash nexus" [Giddings et al., 2002]. Little wonder then that the richer individuals and societies become, the heavier is their pressure on the environment, and all hopes that the environmental pressure would sooner or later rather automatically decline "once we can afford it" (the so-called Environmental Kuznets Hypothesis EKC) have turned out to be just wishful thinking. To the contrary: in the course of their development, the world's richest societies are increasingly degrading the life-sustaining natural systems their very existence depends on.

*"In the course of their development, the world's richest societies are increasingly degrading the life-sustaining natural systems their very existence depends on."*

With economic globalisation, this process has reached a new quality. Mergers and acquisitions have led to an immense capital concentration, and the expected synergies from these friendly or hostile takeovers can only be realised if the standardisation of core components is extended to all products of the respective transnational corporation. So for instance the car frames and the motors are the same in Skoda, Volkswagen, SEAT and AUDI cars, in Fords and Volvos, and only the outer skin, the design is different. The same applies to computers, shoes and banking services: to exploit the economies of scale standardisation is applied, resulting in what looks like a broad variety of products at first glance, but is based on a rather narrow range of basic models and components. Product diversity is created as "pluralism by design", a secondary or virtual diversity of essentially identical products.

On the other hand, eco-labels and standards, environmentally conscious consumers and simple cost concerns have led to a widespread application of life-cycle wide assessments of resource consumption, with the intention to improve the basic design of products and services. Unfortunately, still most such assessments are based on a "cradle-to-grave" philosophy, i.e. they do not focus their attention on the (not cost relevant) resource consumption throughout the use phase and during product disposal or recycling. LCA could play an important role to improve this situation, providing a marketing argument (reduced running cost) to producers and retailers. However, this requires so much rethinking of established attitudes that it will probably need new political initiatives like take back regulations to make business aware of its responsibility not only in ethical, but also in economic terms. Furthermore, even if designed for take back, reuse and recycling, a short lifetime of products could still enhance the total resource consumption; long-lived goods reduce resource squandering, but their market penetration is dependent on a series of social innovations: producers have to realise that they can make money from not producing, but maintaining and upgrading products, consumers have to be convinced that upgraded products are at least as good as new ones (investing in high quality makes more sense if the product is durable), and the maintenance services have to be established on a commercial basis. If this trend ever emerged, the challenge to designers would be enormous, as they would not only be involved in fashionable product design, but in the development of products which may be in need of changing their outer appearance according to the trends of time, while maintaining and improving their function.

## The Driving Forces: Consumerist Consumption

The World Commission on Environment and Development WCED (also known as the Brundtland Commission) has provided the most frequently quoted definition of sustainable development by characterising it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [WCED, 1987, p. 43]. Human needs include basic needs like food, clothing and shelter, but also additional material and non-material demands, which, if satisfied, are supposed to make life more pleasant and entertaining, and a part of these are consumption demands. Others are the challenge of raising children, gaining reputation from voluntary engagement or the satisfaction from pursuing a personal hobby. Which demands are articulated depends on a variety of factors, including the idea of what constitutes quality of life, what is accepted/admired by the social reference groups, or which options are available and affordable. The resulting consumption patterns (including preference formation, purchasing, using and disposing of goods) have significant social and environmental impacts. One task of design-

*"Producers have to realise that they can make money from not producing, but maintaining and upgrading products, consumers have to be convinced that upgraded products are at least as good as new ones."*

ers is to provide tailor-made attractiveness characteristics to be applied to essentially similar goods, to make them suitable to different consumer groups.

A car for example, besides being a sink for resources and a source of pollutants has the effect of a "social presence dilution machine". It permits its owner not to stay put in a certain neighbourhood for living, shopping, consuming and leisure, but to reach out over a significantly larger distance, covering more people. This way, the car owner must be more selective in where to shop, whom to meet and where to go – on the one hand, a gift of choices enhancing individual freedom, on the other a mechanism which contributes to the disintegration of society into different and rather unconnected sub-cultures. Individualism and sub-culture development are at the same time driving forces for increasing mobility demands. Add to this psychological factors like the feeling of independence and the compensation function for unsatisfactory situations in other spheres of life, and the social distinction function of owning a specific car type (the status symbol function is one reason to maintain the virtual diversity), and a permanent need to sustain consumption and to upgrade it results, for cars as for other consumer goods. Their symbolic value, the fetish characters are frequently more important than their initial function as "service delivery machines" [Schmidt-Bleek and Tischner, 1995].

**Figure 8. The car as a product.** *The car has a key role in our economies. Still it is a very odd product: 10 tonnes of resources are turned into 1 tonne of car which transports about 100 kg of humans at an average speed of 15 km/h for an average distance of 1 km per trip (German data). The average German car is used about 200 hours per year for 12 years before it is scrapped as waste. Not much transport service for the resource, or money, input! From another point of view the car allows its owner to consume, and see people or amuse oneself outside his/her neighbourhood – it is a social dilution machine – promoting personal freedom. Or maybe it is a product we do not need, which we buy for money we do not have, to impress people we do not like, a fetish. Photo: European Communities © 2005.*

As a consequence, today many people buy things they don't need with money they don't have to impress people they don't like, regardless of the costs involved and the environmental impact caused. Having this in mind we can rephrase the request for new production and consumption patterns by asking which are the most sustainable satisfiers [Max-Neef, 1991] for the people's needs and wants. Can we substitute the currently used ones for others with a comparable functional quality, causing less environmental and social stress? And as for the wants – are they all equally justified?

What role products and their consumption really play in our societies is still far from fully understood. Whereas rather obviously in a capitalist economy the profit motive is driving the dynamic of growth and innovation on the production side, is money the overall driver for our societies, or just a lubricant? Are humans a-moral utility maximisers, social integration seekers, or fun addicts? What is the driving force on the consumption side? Needs, prestige, distinction, compensation, fun, in which relation to each other? Does consumption really help self-expression, does it provide meaning or identity, or is it just a substitute for immaterial needs [Max-Neef, 1991]? Are we watching the rise and fall of the consumer society [Jackson, 2002]? Which kind of consumption contributes to the quality of life, and which one does not [Daly, 2001]? How can we enjoy the quality of life gains without detrimental effects on the source of all resources, the environment? What in the end is sustainable consumption, what is overconsumption [Miljöverndepartementet, 1995]?

## Sustainable Production and Consumption

The role of consumption for sustainable development has been an issue of heated debate ever since the UNCED conference in Agenda 21 stated that *"the major cause of the continued degradation of the global environment is the unsustainable pattern of consumption and production, particularly in industrialised countries. […] Changing consumption patterns will require a multi pronged strategy focusing on demand, […] reducing wastage and the use of finite resources in the production process"* [United Nations, 1993] – or even before, since Vance Packard published his famous "The Waste Makers" [Packard, 1960]. The OECD [1999] and the United Nations [UNDESA, 1998] developed indicators to assess the sustainability of household consumption as one driving force of unsustainable development, but with methodological weaknesses on side of the OECD [Spangenberg and Lorek, 2002] and limited impact on side of the UN (although since 2002 UNEP is actively working to revive the debate).

In 2002, ten years after the UNCED conference, these efforts culminated in an UNEP proposal during the preparation process of the World Summit for Sustainable Development WSSD in Johannesburg, inspired by the EU, to establish a global 10 years *"work programme on promoting sustainable consumption and production patterns"* [UNEP, 2002]. During the Johannesburg negotiations, however, this was watered down (mainly by US and some pressure from the G7 countries) and ended up in the "Johannesburg Plan of Implementation" [PoI, see WSSD, 2002] as the intention to "encourage and promote the development" of such a plan, based on the "common but differentiated responsibilities" and "where appropriate delinking economic growth and environmental degradation" [PoI § 14]. However, the EU intends to develop such a plan for Europe, setting a precedent for the OECD countries and the global consumer class in general, and the OECD has already published detailed studies on potentials for such a delinkage [OECD, 2001]. Issues to deal with mentioned include the polluter-pays principle (inter alia), life cycle assessment and national indicators for measuring progress ("where appropriate", [PoI § 14a]), and labelling ("where appropriate, on a voluntary basis, effective, transparent, verifiable, non-misleading and non-discriminatory, not to be disguised as trade barriers", [PoI § 14e]).

It remains to be seen if the European Union is really capable of setting something into motion. In the annual synthesis report on the state of the Union and in the corresponding structural indicators sustainable consumption plays no role so far.

## The Driving Forces

For neoclassical economists it is simple: preferences are exogenously given, and they don't change (one wonders why so much money is spent on advertising). With full information, every consumer is a *homo œconomicus*, taking decisions exclusively based on selfish utility maximisation: social or ethical values are not relevant for this "ideal" person's "rational" behaviour. In other words: consumers are all taken to behave like the kind of person you would not invite to dinner, and this is called "rational" (a truly Orwellian use of language).

Reality is more complex, however. Whereas basic needs like food, shelter, etc. are relatively easy to define, the means to satisfy these needs vary considerably between cultures, income groups and gender. Furthermore, the preferences expressed at the counter result from a blend of interwoven intrinsic and extrinsic motivations, deep values and spontaneous emotions, influencing each other and co-evolving over time and income, but with different sensitivities, time scales and levels of resilience (Figure 9).

Products are consumed because buying, owning and/or using them has a personal value for which a monetary value is paid. In determining what is consumed, different spheres of influence overlap; developers, producers, retailers, consumers all have a role to play. The relative level of influence of the different actors depends on social and institutional settings determining their power position, on arguments (including the US-$435 bln turnover of the global advertising industry) and on the responsiveness of their respective audience to these arguments, which is influenced by a variety of intrinsic and extrinsic factors.

Intrinsic factors comprise cognitive capacities, psychological factors, individual interests and philosophical or ethical norms, whereas extrinsic factors include socio-economic aspects like the disposable income and time availability as well as social relations (self esteem, respect, family bargaining). Intrinsic factors determine the preferences, while extrinsic ones reflect the economic, social and legal possibilities and constraints determining which preferences can be realised. As both overlap (e.g. individual preferences are shaped by social norms and relations and vice versa) no quantitative determination of the relative importance of both for the resulting behaviour is possible; they co-evolve [Hinterberger and Stewen, 2001].

Regarding private consumption, while extrinsic factors like disposable income have a significant influence on the availability of consumption options, intrinsic factors shape the choice between the alternatives available. One key factor determining such decisions is the individual assessment if existing alternatives are affordable in terms of purchasing power, time use preferences, resource endowment, social status and acceptability, legal and ethical constraints, and the value at-

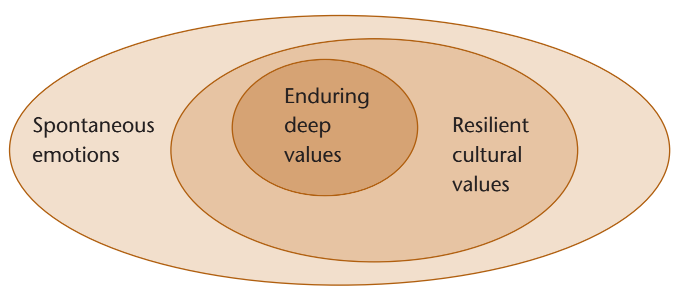


**Figure 9. Values, motivation and their resilience**. *To understand why people consume we need to look at deeper values. Basic values are shelter, food, health, mobility and education; we buy products, which help us to fulfil these values. However the products may be very different, and are so in different cultures. Long term, resilient, cultural values are expressed in various products, while short term values, or rather emotions, are expressed in different products, although overlaps are possible. [Nielsen 2002, modified].*

tributed to a certain consumer item by the potential customer. From its very root, value (from Latin "valere") means to have strength and meaning. However, meaning is not inherent in products, but a symbolic function attributed to them by society and its value systems (stimulated e.g. by advertising), or by a specific group. Products can be reflections or symbols of group identity, reflecting the *visions, leitbilder, grand narratives or concrete utopias* a group like a nation, an ethnic group, or a lifestyle based subgroup has, the idea of quality of life they share and live. Exposing a certain good (owned or borrowed) can thus symbolise membership of a certain group (or the aspiration to be a member), support for a certain idea, etc.: products do not create identity, but they are indispensable tools to express it. Expressing identity as an active act creates in turn the opportunity to experience one's identity, an extremely positive effect made possible by exhibiting certain products (and extremely frustrating to those who wish to join this group, but cannot).

Thus products provide solutions to problems and meaning to every day life; both, the problems to be solved and the suitable solutions, and the visions and the meaning derived from them change over time. They have to adapt to changing circumstances to avoid a lock-in, in order not to be fixed to quasi-sacred consumption patterns, as is the case e.g. with the "American way of life". President Bush senior made this clear when he came to Rio de Janeiro in 1992 to join the UNCED conference, stating that "the American way of life is not up for negotiation". Such a sclerotic consumption pattern, combined with the insight into the limits to resource availability, i.e. embarking on the "full world paradigm" [Daly, 1996] and realising the restrictions this implies, makes an imperial attitude fully plausible as a means to safeguard the supply of those resources needed to maintain the prevalent consumption pattern.

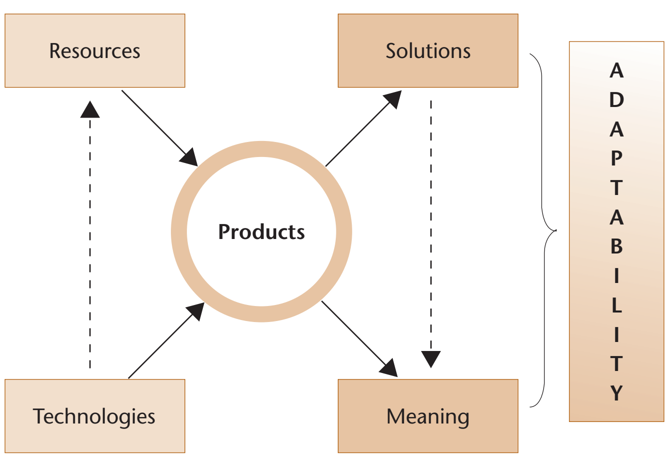


**Figure 10. Societal evolution and adaptation.** *New solutions, through technological development and new use of resources, and development of meaning, drive the evolution of a society to adapt to changing conditions, e.g. environmental requirements [Nielsen, 2002].*

This attitude has significant social and psychological implications; for instance, every empire perceives the rest of the World as full of enemies and feels the need to protect itself against them by imperial means, whereas a different worldview based on fair partnership would consider them to be (more or less pleasant) negotiation partners. The latter view, however, needs the adaptability arising from evolving solutions and meanings, an openness to new knowledge and the willingness to learn (Figure 10). In this sense the sustainable knowledge-based society offers a different paradigm and an alternative to the expansionist, resource squandering current consumer society, based on a new *leitbild* or vision of optimality, not maximality [Daly, 1991]. Adaptability has even more implications: it demands – like sustainable development – a rather high level of social justice and equity, as social stratification leads to higher consumption pressures [Fischer-Kowalski and Haberl, 1997].

## The Evolution of Preferences

Whereas in the pursuit of happiness during the 1950s and 60s the quantity of consumption was taken as a measure of its quality, in the 1970s its social attributes, in the 1980s its price and in the 1990s its fun-factor defined its added value for the quality of life. At the turn of century the consumption drive has been slowing down, the risks of life (stock exchange losses, terrorism and war) dominated the public mood, while the quality of life seems to be re-emerging as a core motive in the first decade of the new century. However, only time will tell whether this will result in another turn in the 300-year-old competition of paradigms between sustainability and expansionism [Grober, 2002]. A move from the high-throughput consumption society attitude of *"to buy is to be"* to the wealthy, value-based durability promoting *"to have is to be"* is possible if not plausible, and the rather philosophical attitude of *"to be is to have"* is lurking in the visions of a sustainable knowledge-based society where social status is more based on knowledge than on the possession of material goods.

A turn around is neither easy to achieve nor to be expected without deliberately investing significant political, scientific, technological and educational efforts. Less resource-consuming products and services are possible, as the examples of resource squandering service provision earlier in this paper have illustrated. So far, however, we are caught in a "catch 22" situation: producers and retailers offer only a few and not too radically dematerialised goods and services, claiming that "there is no market for alternatives", while consumer and environmental NGOs put the blame on the business sector for not offering suitable options. As long as to the consumer *"the enemy of the good is the cheaper"* rather than the better (whatever the definition of "better" may be), political interventions to *"get the prices right"* [von Weizsäcker, 1994] will be a necessary means of adjusting consumption and production trajectories to environmental needs.

Such adjustments are not only a matter of political will and determination, as technological, social and economic development cannot change course at will at any time, but are restricted by the fact that they have embarked on path-dependent development processes and developed specific technology trajectories. In this perspective, the strategic challenge of sustainable development is to use, to find or even to create bifurcations permitting us to leave the established socio-economic trajectories and change course towards a new paradigm. This can be based on the values expressed by ordinary people when asked for their most prominent wishes and aspirations: health and fitness, work and social security, education and information, a social environment providing acknowledgement and contact, and last but not least a healthy environment. Unlimited consumption, wealth or only a high income level are not on the wish list – they are means for security and well being, but no ends in themselves.

## Towards Sustainable Consumption

Nonetheless consumers have a certain responsibility for environmental degradation through their purchasing and use patterns – however, how much this is, e.g. as compared to public authorities, producers and retailers etc. cannot be quantified. The reason is simple: although it is possible to calculate the resource consumption for each major consumption area (like housing, nutrition, mobility, health, education), the pattern of influence and thus of responsibility varies between individuals, over time and between regions, cultures and gender: no simple percentage figure will ever be able to reflect this dynamics, let alone the overlapping spheres of influence of different actors. However, this is not to say that no assessment can be made at all, but it must take a different form from allocating a specific and quantifiable share of responsibility to households. To achieve this, it is essential to distinguish between those fields of household consumption that are environmentally dominant (as are the five listed above) and others of minor environmental relevance (clothing, hygiene, leisure without transport, and fashion). In a second step, common sense and educated guesswork help to find out which of the five fields are really shaped by household decisions, and which ones are dominated by other actors. As a result, construction and housing, nutrition and mobility turn out to be the three priority fields for household sustainability [Spangenberg and Lorek, 2002].

However, each of these fields is constituted by a number of activities which are influenced by different actors in a rather differentiated way. So once the most important activities have been identified, we are down to earth again and can describe the decision-making situations including the weight of different actors, e.g. on an ordinal scale from "0" to "++" [Lorek and Spangenberg, 2001]. These actors include households on the demand side, and planners, architects, producers, advertisers and regulators on the supply side.

> ***"The values expressed by ordinary people when asked for their most prominent wishes and aspirations: health and fitness, work and social security, education and information, a social environment providing acknowledgement and contact, and last but not least a healthy environment. Unlimited consumption, wealth or only a high income level are not on the wish list – they are means for security and well being, but no ends in themselves."***

For all economic actors, however, business and consumers alike, the framework conditions must be set to support sustainable consumption if a change of the status quo is to be expected. Whereas today "green products" have established themselves in a variety of niche markets, for a broader effect a level playing ground must be provided. This includes setting general environmental minimum standards for all products, be it by means of legal regulation of product characteristics or producer liability, or by voluntary action as a result of consumer pressure. However, in the latter case of "agree and control" instead of "command and control" the control becomes all the more important, not least to shake off free riders. Although it may sound surprising, this includes developing and marketing consumer items which are environmentally sound but *do not*

### Household Consumption

It is essential to distinguish between those fields of household consumption that are **environmentally dominant** (housing, nutrition, mobility, health, education) and others of **minor environmental relevance** (clothing, hygiene, leisure without transport, and fashion).

*look like it*, in other words: which have no predefined image. As long as consumers use products to project their dreams and identities, a product with a given image will only be attractive to those who agree with these priorities, while it will be rejected by the others (the majority). An "unidentifiable environmental object", on the other hand, permits projection of whatever lifestyle and value the consumers may have, and the environmental soundness can be marketed as an added value, a feel-good-factor: "take it for other reasons, and don't worry about the environment". In the end, consumer preferences are one thing, and the political preferences expressed by the same individuals as citizens are another, determining which kind of environmental policy will be implemented. At least in one respect they have to make a choice for sustainable development, as business and politics in a democratic society and a market economy will not be a driving force towards sustainability as long as consumers and citizens do not demand it.

**Figure 11. To meet the sustainability challenge with creativity.** *"When the winds of change start to blow, some people begin to build wind breakers, but others build windmills." The environmental challenge can be met by ingenuity. A wind power station is producing high value electricity with a footprint that is some 100 times lower than e.g. biofuel, but with a significant TMR. Photo: Vattenfall/Hans Blomberg.*

## Outlook

Sustainability is not an ideological blueprint for a future society: nobody knows what the future will look like, although we are all involved in creating it. For this creation process we need an orientation, a compass indicating the direction of what

***"At least in one respect they have to make a choice for sustainable development, as business and politics in a democratic society and a market economy will not be a driving force towards sustainability as long as consumers and citizens do not demand it."***

is probably sustainable in the long run (i.e. also for future generations, and if applied to all the Earth's citizens) and what is definitely not. For implementing this insight, for making it operational and relevant in day-to-day decision making we need a democratic, highly participative political process to translate the general orientation, based on the values of the society, into concrete strategies and policy measures. The result is still open, but probably, as the philosopher A. Andersch put it, "the future will be less different from today than we now expect – the present situation, however, is rather different from how we still perceive it". We are all invited to develop solutions today which will shape a sustainable society tomorrow. "You'll be done with tomorrow if your only concern is today", public wisdom says. But there are alternatives: "When the winds of change start to blow, some people begin to build wind breakers, but other build windmills".

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*http://www.seri.at*

# 1 Environment and Design

## 1.1 Ecodesign: A Key Step Towards Sustainable Development

Modern life leads to an enormous impact on the environment. Currently, we 'spend' far more environment than we have. We may of course blame our lifestyle for this situation, but just as much it is due to how production and consumption are organised and carried out, and how products are shaped and used in our societies.

To secure a good future, we must reduce the negative impact on the environment. All kinds of actions that contribute to this aim are important. In production and consumption we need to look at all steps from resource extraction, to treatment of emissions during the manufacturing process of a product, its use, and the reduction of the impact of the product waste. Production and consumption, however, are not only of concern to the environment. They are also at the heart of the economy of companies and society as a whole, and the social situation for citizens. The challenge is thus to reduce environmental impact, and at the same time maintain a viable economic life and social well-being, that is to pursue a *sustainable development*.

One important answer to this challenge is provided by *ecodesign*, also called *Design for the Environment*, DfE. Ecodesign may perhaps be the most comprehensive response to the problem of "our spending far more of the environment than we have". It aims to achieve a profitable balance between ecological and economic requirements in our societies, through the proper design of products.

Ecodesign thus pursues the integration of environmental (ecological), social (fairness) and business (financial) objectives of production, also known as *the three P's: Planet, People, and Profit*. Already here, however, it should be said that to approach all three P's successfully, it's necessary to add one more P: the P of Politics. All programs and actions are doomed

**Ecodesign focuses on:**

actions aimed at environmental improvement of products during the initial design phase through functional enhancement, selection of material with lower impact, application of alternative processes, improvement of transportation and use, and minimisation of impact during the end treatment stage.

**In this Chapter**

to fail if there is no support on the political level. Later in the book (Chapter 15 as well as the end of Chapter 4) we will return to how politics, in fact governments, are involved and what their responsibilities are.

Ecodesign has been developed to incorporate new concepts, such as the vision of a product-system, the concept of *life cycle* and *integration of all players, stakeholders,* involved. It begins with the improvement of the environmental aspects of the products, and expands to include several actions on environmental issues, such as waste treatment, recycling and cleaner production, and later also integrates financial, such as eco-efficiency, and socio-economic aspects into product development.

In short, ecodesign is an internationally recognised approach to *reduce the environmental impact of products through design*. The total life cycle of a product is the basis on which ecodesign builds its strategies. From the cradle to the grave (or better: from cradle-to-cradle), environmental issues are considered for each stage the product goes through.

## 1.2 A New Policy for Companies

### 1.2.1 More than Environmentally Friendly

The concept of sustainability has today in many situations superseded the concept of "green technologies" or those that are simply "environmentally friendly". Many major companies accept the case for including "sustainability" within all aspects of their activities. They can identify new business opportunities and cost savings from doing this.

The concepts involved include environmental, economic, social, and also technical elements. The application of novel approaches to improve the ways in which people live, interact with the environment and consume products and services is therefore not always straightforward. Not only is a multi-disciplinary approach required, but also a flexible, broad and integrative perspective. It is a challenge for professionals charged with the responsibility of advancing ideas and techniques to promote greater sustainability in our societies.

### 1.2.2 Integrated Product Policy (IPP) and Producer Responsibility

For some time now, the European Commission has been changing its traditional, mostly economic, policy of production to a more ecological one. In this work it aims to integrate all aspects of production and consumption. When applied to products, the new approach is based on a so-called *Integrated Product Policy, IPP*. It requires that companies adopt a "cradle-to-cradle" approach, with responsibility for recovery and recycling of artefacts that have come to the end of their useful life.

Most of the design and manufacturing processes are today either controlled or regulated by standards and regulations or directives of the Commission. In order to continue to improve the level of environmental performance of products entering the European marketplace, further action is focusing on the relationship between products and their burden on the environment throughout the whole life cycle of the product. This is expressed in the so-called *Producer Responsibility*. It is a policy in which manufacturers of physical products undertake liability (legal responsibility) for end-of-life waste management of their products. It is a key step designed to bring the short-term and long-term equilibriums of products into some form of proximity with each other.

Producer responsibility cannot drive that process in isolation. It needs a holistic and integrated approach, creating a set of *price signals* that encourages improved resource efficiency of all players in society. Those other measures include:

- End-of-life fiscal instruments (disposal taxes, discharge bans, etc).
- Increased regulatory costs (integrated pollution prevention control, fines and prosecutions).
- Virgin input costs (taxes on raw material consumption).

The whole system is held together by the "glue" of traded permits at appropriate stages of the supply chain. The former – disposal taxes, discharge bans – aim to reduce impact at the

**Figure 1.1 Producer responsibility.** *Producer responsibility, sometimes called extended producer responsibility, states that the producer has to take back the product when it is to be wasted. This might be a far reaching change for the producer, e.g. for the electronics industry, or in general for products which contain toxic or hazardous materials, such as CFCs in refrigerators. Photo: Holmes Environmental Ltd.*

end of the life span of a product. The latter – taxes on raw material consumption – are demand-side issues aimed at reducing the consumption of resources.

Producer responsibility, or Integrated Product Policy (IPP), is far more interesting and significant than the earlier environmental policy in EU. It seeks to go to the heart of supply-side factors by encouraging an increasingly globalised and oligopolistic production sector to undertake a fundamental review of the way their products are engineered, put together and marketed. IPP achieves this by the simple mechanism of obliging manufacturers of consumer capital goods, for instance, to incorporate end-of-life collection, dismantling and environmental neutralisation as another element of production costs.

### 1.2.3 Consequences for the Price of the Product

A central challenge for industry is to include all environmental costs of a product in its price, and doing this without risking its economy. Currently the end-of-life costs tend to be paid for by the last user in the chain. One needs to find a way *to transfer these end-of-life costs to the first user in the chain* and thus the original selling price of the product. Not to let the price grow high in a price-competitive market, the manufacturer has to see to it that the environmental cost of its product, as waste at some point in the future, is minimised. This is done through redesign, including e.g. weight reduction, reductions in toxicity, and improved labelling of components to allow recovery and reuse.

Analysis of the cost of that transfer, as a percentage of the turnover, suggests that around 2-3 per cent is added to the price of high-cost products, such as pharmaceuticals, and more for low-cost products such as newsprint or plastic packaging. Overall it may not sound like much, but the cost of delivering environmental improvement through this route is potentially equivalent to existing levels of profit before interest and taxation (PBIT) returns in many industries. Clearly something has to give. Otherwise it is obvious that the consumers will have to pay for improved environmental management.

### 1.2.4 Economic Instruments to Protect the Environment

There are many different economic instruments used by the state to reduce the environmental impact of production. This includes:

- Charges for scrapping a product, such as land fill tax.
- Taxes on energy.
- Road pricing schemes to reduce transport.

There are today some efforts to coordinate all these mechanisms into a transparent framework aimed at developing best or better practices. They are part of the so-called *green tax shift*, in which income tax is reduced when environmental tax is increased.

Economic instruments will have very different consequences for different industrial sectors. Thus some sectors that use large amounts of energy will be greatly influenced by energy taxes, and others where waste production is large, will be greatly influenced by waste charges. Various approaches are today being discussed to make it realistic for these sectors to develop better environmental profiles, very often through state support during at least a transitional period.

## 1.3 Consumers and Markets

### 1.3.1 The Consumer Role in the Product Life

There are a number of reasons for the growing interest in product-focused measures. One important reason is the fact that *the relative importance of consumption-related emissions and wastes is rising*. Controls of production processes have been successful in reducing industrial pollution, and will continue to be a vital part of the strategy. Increasingly, however, in many areas environmental benefits will be much greater from consumption-related rather than production-related measures.

A good example is that of the energy use for electronic products, where the use phase is much more important. Another classic one is that of a car, where the energy consumption during the use phase is very considerable.

IPP thinking addresses the possibility of controlling impacts during the entire life cycle of a product, not least the use and waste phases. This process will necessarily be more

**Table 1.1** *Examples of possible instruments in the integrated product policy toolbox.*

| Instruments | Including |
|---|---|
| Voluntary instruments | Voluntary agreements<br>Self-commitments<br>Industry awards |
| Voluntary information Instruments | Eco-labels<br>Product profiles<br>Product declarations |
| Compulsory Information Instruments | Warning labels<br>Information responsibility<br>Reporting requirements |
| Economic instruments | Product taxes and charges<br>Subsidies<br>Deposit/refund schemes<br>Financial responsibility |
| Regulatory Instruments | Bans/phase-outs<br>Product requirements<br>Mandatory take-back |

## Box 1.1 Design

In everyday use design refers to the *form or shape* and *colour* of products, or whole settings such as a room or a building. It is conceived as art or aesthetics. This is especially clear in e.g. graphic design, which only refers to form and colour. Also the choice of *material*, textile, wood, plastic, metal and so on, is understood as part of the design of a product. This is especially clear in the design of consumer products or *industrial design*. Rather early, design started to include also *function*. A well-designed product should thus be easy to use and functional. It is more recently that design also takes the *environmental properties* of a product into account. Ecodesign or design for the environment, DfE, which deals with this, is often the responsibility of another person than the designer. More recently *design education* includes some ecodesign although this is much weaker than the traditional components of the training. Today, when design is of crucial importance for everything from to TV-sets to cars and other technically complicated products, this interdisciplinary training becomes even more essential.

There is seldom a conflict between traditional and new concerns in design. The classical values of design very often overlap with the environmental ones. A good material of a product is also often environmentally friendly. If a product is dependable it is more long-lived which is good for the environment. If it is beautiful rather than trendy it will also last longer and be better taken care of, which again is good for the environment. One may refer to design in the agricultural society. Tools and utensils were very often both of high quality, beautifully decorated, functional and lasted long. It was design for beauty, function and environment.

**Figure 1.2** *A well-designed dish brush, which is both functional and environmentally friendly.*

complex than the traditional policy. Traditional policy focuses more on the control of sites and materials, because its application ranges across whole product sectors and is shaped to fit their particular market circumstances. *The IPP concept applies a range of policy instruments, in a coordinated, integrated and complementary manner.* The instruments would come from a large toolbox of different policy instruments, ranging from voluntary agreements to direct legislation. Table 1.1 gives examples of possible instruments in the IPP toolbox. This toolbox is not exhaustive. New instruments should continually be developed to suit specific purposes and situations.

For the future, we may expect legislation/voluntary agreements, related to any industry's products, bringing together controls over materials usage, end-of-life management, energy consumption, etc. Future legislation will probably include measures to promote:

- The integration of a product focus into all relevant EU policy (both environmental and general).
- The use of "market mechanisms" to encourage better producer responsibility.
- The encouragement of markets for green products.
- Enhanced dissemination of environmental information.

While it is too early at this stage to have a clear picture of the implications of IPP on industry, it is certain that the IPP approach could have important implications for the design, development, manufacturing, shipping, marketing and selling of products in Europe.

### 1.3.2 Product Design and Customer Requirements

The integrated relationship between marketing and design is paramount in *developing products that conform to customers' specifications and requirements*. Marketing provides the data which designers use to develop products. Without a close relationship, the design of a product/service is not effective, and a customer would move to competitors´ products/services.

"Fitness for purpose" is a concept first described by Deming in 1986. It has connotations similar to those given by Juran's ideas in 1974: "Fitness for use" and Crosby's in 1979: "Conformance to requirements". Peter Drucker, in his book *Managing in Turbulent Times*, tells us that the survivors, public and private, in today's competitive environment will distinguish themselves in customers' minds either through clear product superiority, exceptional service or both. Providing products or services that continuously meet customer needs will require that the whole organisation become quality-oriented and consequently customer-oriented.

Quality can no longer be seen as just meeting customer requirements. It is a continuous search for added value for customer requirements. This requires careful marketing to ensure that those needs, stated or implied, are provided as a meaningful basis for the design of the product or service. Organisational efforts must be directed towards what the customer expects, not what the organisation thinks the customer expects.

### 1.3.3 Product Design and Marketing

Except as a source of customer requirements, quality is almost never mentioned in the literature, or discussed at quality conferences. Few organisations seem to be actively pursuing quality in their marketing functions. This apparent omission of marketing from the commitment to quality does not seem appropriate. Marketing is usually the customer's first contact with the organisation, and therefore, marketing is responsible for selling not only the product or service, but the organisation as well.

In a product-driven organisation, engineers and designers have often taken the position that "our products are so good, they sell themselves". They fail to recognise the requirements for effective marketing, which must be customer-based. Marketing plays a vital role in every organisation and the potential for improvement appears to be significant.

So, how can you briefly define marketing?

Marketing is providing a product or service to satisfy customer needs, at a profit. Marketing is the social and managerial process by which individuals and groups obtain what they need and want through creating and exchanging products with others (Kotler, 1991).

In a quality-oriented organisation, marketing is more than the selling function. It is about the provision of meaningful data from which to develop products and services, and supplying those products and services that continuously satisfy customers' requirements.

In the quality marketing-oriented organisation, the customer is the focus; whereas in the manufacturing-centred organisation, they consider that the internal product is the focus and customers will follow.

## 1.4 The Design Process

### 1.4.1 Design for Quality

Designing a high-tech product used to take many years, e.g. motor vehicles used to take up to seven years to develop from conception to the first production model. Now, even with high-tech and very complex products, the design and first production unit coming off the production line can be between one and three years. Design affects how soon the customers get what they want, and what technology they can have.

Design, as a process, has been severely confined as a management strategy for delivering products that conform to customers' specifications. Now that the quality revolution is here, the design element of quality management provides a major influence on ensuring and achieving quality products/services that sell. Design of products/services, and the processes that contribute to their enhancement, will be more constructive in

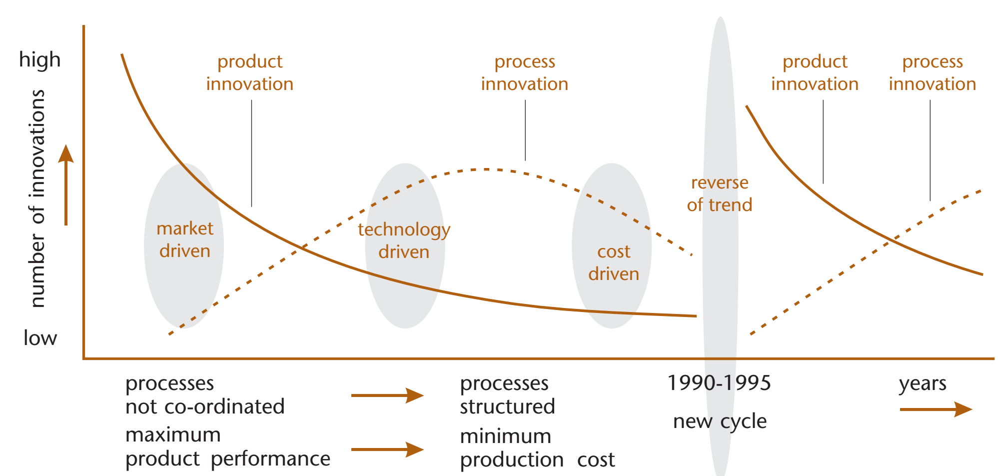



**Figure 1.3 Producer focus in the product life cycle.** *In the 1980s the focus of many companies was to improve the manufacturing process (process innovation), from the earlier emphasis on the product (product innovation). Recently it has changed again and today the process, such as in cleaner technology, is important [based on Korbijn, 1999 and Pugh, 1991].*

the long run, in terms of costs to the organisation and value for money to the customer.

Designing for quality is now seen as a competitive weapon. Designing what the customer wants provides opportunities for design engineers and marketers to enter into the quality management arena and take their rightful place.

### 1.4.2 Innovation of Design

Generally you can say that innovation of design is Renewing Product Development (RPD), or Environmentally friendly Product Development (EPD). This means that the environment influenced the decision-making in the design process, and directly influences the final product design – the environment has the function of a co-pilot.

In this way the environment takes a place within "traditional" industrial values like economy, functionality, aesthetics, ergonomics and image. The position of the environment within the traditional industrial values differs in different companies and is re-evaluated with the increasing experiences of it and the external pressures. With ecodesign you can demonstrate:

- Awareness and the need of environmentally friendly product development.
- Clarity of (design) results by the involvement of the environment in the product development process.
- Availability of methods for environmentally friendly product development for designers.

Beside the introduction of ecodesign as part of their innovation strategy, companies have to develop their products

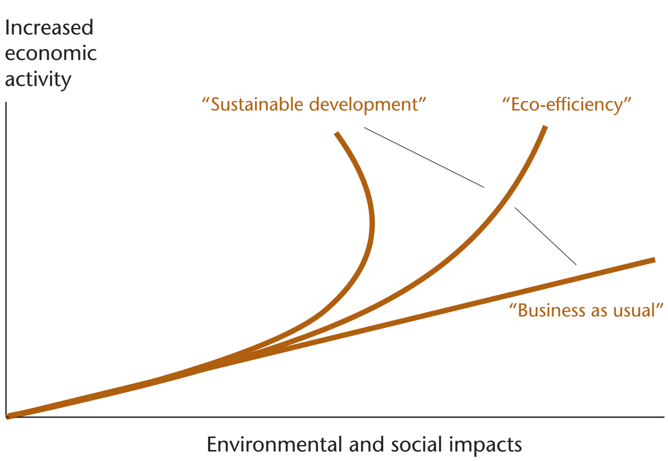



**Figure 1.4 Economic growth and environmental impact.** *In early industrialisation economic growth leads to increased environmental impact. Later a certain decoupling of economic growth from environmental impact (also called eco-efficiency) occurs. However for sustainable development a much larger decoupling is required [based on Hillary and Jolly, 2001].*

even faster, while the products themselves become more knowledge-intensive and more complex. Therefore it becomes increasingly important to put all internal and external sources of knowledge and information into a system of good use: knowledge management. Examples of external sources are experience and craftsmanship. Since this kind of knowledge is particularly valuable for a company, the management and applications of this knowledge should focus on human resources and human capital. The sharing of knowledge must be stimulated by management. The more knowledge is put into products, the more important the quality of that knowledge is.

### 1.4.3 Product Development

A competitive manufacturing industry is of great importance to national economies. To remain competitive in this sector, great effort is required in response to the short period of time in which companies must develop their products. For instance, the market has changed from being driven by supply to being driven by demand. The customer truly rules and increasingly desires tailored products. This has reduced the predictability of the market, forcing companies to be highly flexible.

The enormous technical dynamics allow products to enter the market faster. Together with intensive globalisation, this in turn leads to stiff competition. Therefore, in addition to speeding up, efficiency, quality, innovation and the power to distinguish oneself from the market players all become increasingly important.

Knowledge quickly becomes obsolete under such rapidly changing circumstances, so companies must specialise. Therefore they often return to their core competence. As a result, more collaboration is required.

Also, circumstances such as globalisation and sustainable development as well as products themselves become ever more complex.

To be armed in this battle many companies in the seventies and eighties improved their manufacturing processes. This approach is no longer sufficient. At the beginning of the 21st century, decisive action will shift to the product creation process (Figure 1.3). Product creation is sometimes called the industrial battleground of the coming decades. Companies, which can excel through their product creation processes, have a golden future ahead. Some success factors are discussed below. The conceptualisation and development of products must be cleared from the mystical aura of occupational ingenuity. Notwithstanding the need for personal creativity, product development must be systematised to an integral, well-structured and managed product-creation process with a focus on collaboration, knowledge management and learning. Increasingly, technical tools become available to assist in this, but that is not all. A world-class product creation process is not just the responsibility of the technical departments. On the contrary, it requires effort and dedication of all key processes in a company. Thus, the organisation and structure of companies must be changed too, sometimes drastically.

## 1.5 Controlling Environmental Impact in Production

### 1.5.1 Integrated Pollution Prevention and Control (IPPC)

Until the mid 1970s we lived in a world where resource depletion and pollution were seen to be of limited importance. The following decades, however, brought an increasing range of pollution control regulations and with it an era of *end-of-pipe* environmental technologies to reduce environmental impact from productions.

In the late 1980s and the 1990s there was a shift towards more preventive regulation and an increasing awareness of *eco-efficiency* concepts such as *waste minimisation* and *energy efficiency*. This coincided with a move towards improved quality management, and hence companies began to look for technologies that brought environmental and/or workplace benefits along with quality and efficiency improvements. Businesses therefore began adopting systems that:

- Produced better quality products.
- Maximised material yield and minimised losses.
- Used less energy and water.
- Took up less space on the shop floor.
- Were simpler and cheaper to operate and maintain.
- Were inherently cleaner, producing less pollution and improving shop-floor conditions.

These so-called *cleaner technologies* therefore encompass all sorts of "regular" processes, and adopt them to a less damaging "eco-efficiency" growth path (Figure 1.4).

The environmental authorities supported and pushed this development with legal and economic measures, such as emission charges, waste charges, resource taxation etc. However they have mostly been piecemeal and un-coordinated, solving one problem at a time. In the efforts to integrate these measures the European Commission has developed the IPPC Directive. IPPC stands for *Integrated Pollution Prevention and Control*.

A new system of pollution control! Another batch of Regulations! Another Directive! A hard-pressed industrialist may well be forgiven for thinking that he/she does not need this. However, there is much in IPPC that industries do already. IPPC is an integrated method for developing certificates (permits) for industries and other activities which may cause environmental disturbances. In addition the principles on which it is based are consistent with good business management principles.

Integrated Pollution Prevention Control thus applies an integrated environmental approach to the regulation of certain industrial activities. This means that emissions to air and water (including discharges to sewer and land) plus a range of other environmental and social effects, must be considered together. It also means that regulators and authorities must set permit conditions so as to achieve a high level of protection for the environment as a whole. These conditions are firmly based on the concept of using *the best available techniques, BAT*, which balances the cost to the operator against the benefits to the environment. IPPC aims to prevent the emissions and waste production and, where this is not practicable, to reduce them to acceptable levels. IPPC also takes the integrated approach from the initial permit through to the restoration of sites when industrial activities cease.

IPPC is based on the idea that *operators have responsibilities for what they do*. Operators know what to produce to satisfy the market. They need to be responsible for the consequences of this and produce their products with a minimum of disturbance to others.

### 1.5.2 The Technologies of Eco-efficiency and Cleaner Production

The "end-of-pipe" technologies, while originally aimed at cleaning up emissions prior to discharge, have begun to play an increasingly important role in terms of resource recovery. Important technologies in this regard include:

- Settlement/centrifugation/flotation (to separate high/low density materials from water/air).
- Membrane filtration (physical separation for a wide variety of materials).
- Ion exchange (e.g. for recovery of metals and electrically charged coatings).
- Evaporation/condensation/distillation (e.g. solvent recovery from waste coatings).
- Adsorption/desorption (e.g. solvent capture and recovery from gas streams).

While all of these technologies have made a very significant impact, it is perhaps membrane systems that have been applied most widely; they are found in many sectors including chemicals, pharmaceuticals, textiles, metal finishing, ceramics, food and drink, paper/pulp and chipboard/fibreboard manufacture. The type of membrane varies from simple cloth-type microfilters, to concentrate such materials as latex, oils, paint pigments, etc, to sophisticated polymer ‹nano› and reverse osmosis filters that can take out very tiny particles (down to less than 0.001 of a micron) including metal ions, dyes, artificial flavours and various organic molecules.

Cleaner production thus will have some consequences for the design of products. Surface materials may be different in some cases, products will be dematerialised when possible, and the composition may be less complex than otherwise. In most cases CP methods will however not influence the products, just production.

## 1.6 Future Prospects for Ecodesign

The move to ecodesign is a difficult one for enterprises, since it requires a new way of overall thinking and working. Managers and technicians find it difficult to move from a culture based on localised thinking and environmental strategies of treatment (T) and recycling (R) to a process of ecodesign (E). It requires a new culture, with a new organisation of work including participation of workers in the process of development of Ecoproducts.

In order to make this change a reality, governments must take further action within the framework of the Integrated Product Policy (IPP). We need programmes promoting R&D in ecodesign and awareness of Ecoproducts. We need the creation of environmental databases, and stimulation of university training in ecodesign issues. We want to see promotion and awareness campaigns focusing on Ecoproducts and compulsory green purchasing. Another factor that will speed the process will be increased pressure from European consumers, who are increasingly aware of environmental issues (Figure 1.5).

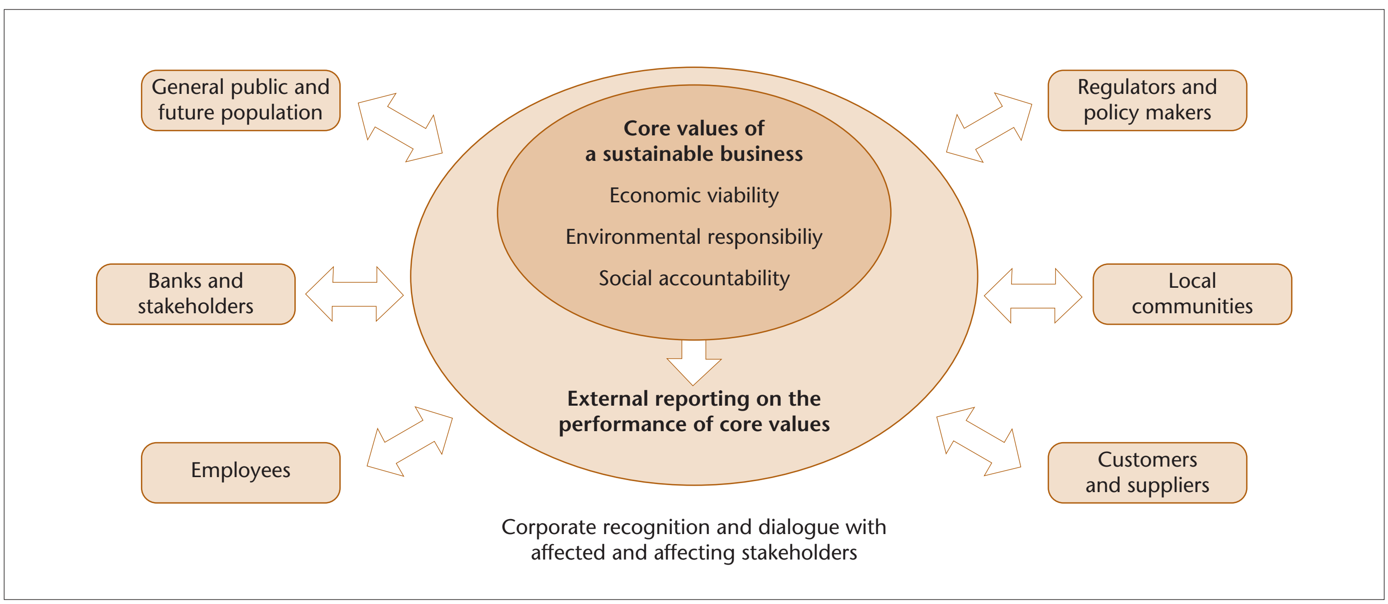



**Figure 1.5 Corporate governance for the 21st Century.** *Companies are today increasingly influenced by both traditional (investors, policy makers, customers, etc) and non-traditional (general public, local communities, etc,) stakeholders. These stakeholders will influence their environmental performance and their products, as requests for eco-labelling, environmental certification, and corporate responsibility are pronounced [Hillary and Jolly., 2001].*

## Integrated Product Policy

***The European Parliament adopted on the 21st of April 2004 a resolution based on the report drafted by MP Anders Wijkman. An extract of the text follows below.***

We are welcoming the IPP communication but regretting that it provides only limited guidance on how to move society in the direction of truly sustainable systems of product development and design. It called on the Commission to present a framework directive for IPP…. aimed at facilitating business practices which should be built on systems thinking, giving priority to resource efficiency and should be structured progressively along biological lines.

The main principles guiding the IPP framework have to be based on:

- A systems-based approach, where life-cycle thinking is at the core and primary attention is given to product design.
- An enhanced understanding of how natural systems work and of how structuring business along biological lines can both improve the environment and establish the bottom line.
- Ensuring that products whose useful life is over should ideally not become useless waste but be separated and reconditioned to become inputs for new production cycles.
- An enhanced understanding of how consumption patterns are formed and how they can be changed to contribute to sustainable development.
- Optimisation of the product design process, by the selection of low-impact materials.
- Giving preference to bio-based materials; moreover, hazardous substances, including many heavy metals, should not be allowed systematically to increase in concentration in the biosphere; furthermore, chemicals should be used in a non-dissipatory way; safety of chemicals should be assessed through a science-based hazard and/or risk-approach. Priority should be given, however, to the substitution principle, meaning that hazardous substances including many heavy metals should preferably be replaced by more benign ones or safeguarded through tightly controlled closed-loop recycling.
- Optimisation of production techniques, by giving preference to the clustering of production by encouraging reuse and recycling of materials, in particular by developing techniques for the separation and reconditioning of used products and materials to become input for new production cycles.
- Reduction of impact during use.
- Making full use of the potential offered by ICT to promote miniaturisation and dematerialisation, enhancing energy and material efficiency and reducing transport demand by turning products into sustainable services.
- Maximum involvement of stakeholders.

The short-term objectives for the IPP framework should be focused on reductions in emissions of greenhouse, acidifying gases and air pollutants, reductions in energy intensity, reductions in the use of hazardous substances, reductions in the intensity of virgin material resource use, water use and waste production and increase in renewable material use.

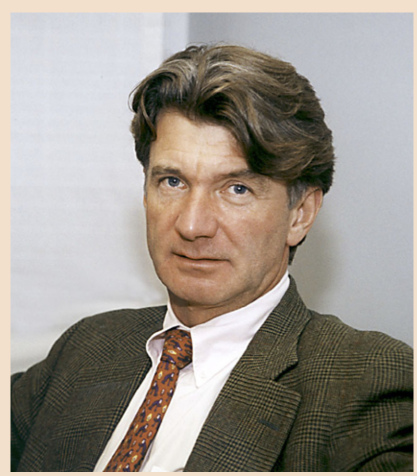
Without the creation of such a framework, the necessary signals and incentives are not put across to designers and decision makers.

**Background**

The original *Green Paper* on Integrated Product Policy, IPP, was adopted by the European Commission in 2001. It was followed by a series of studies and debates on the environmental impacts of products and possible measures. In 2003 the Commission adopted a *Communication* on IPP, which indicated how the Commission intended to develop the area. Among the reactions on the Communication was the *European Parliament Resolution* on IPP adopted in 2004, here cited. The Commission launched in mid 2005 its *European Platform on Life Cycle Assessment*, motivated by studies suggesting that LCA provide the best framework for assessing the potential environmental impacts of products currently available.

**See further:**

*http://europa.eu.int/comm/environment/ipp/home.htm*



*MP Anders Wijkman.*

## Study Questions

1. Discuss how ecodesign may contribute to a sustainable development.
2. Which policy instruments (tools) are available to promote ecodesign?
3. What kind of difficulties do you expect when these tools/instruments are used?
4. Describe what role quality, innovation and product development plays in the design process.
5. How can the environmental impact of production be controlled and reduced?
6. Discuss how ecodesign may develop in the future.

## Abbreviations

| | |
|---|---|
| BAT | Best Available Techniques. |
| CP | Cleaner Production. |
| EfD | Environmental friendly Design |
| EPD | Environmentally friendly Product Development. |
| IPP | Integrated Product Policy. |
| IPPC | Integrated Pollution Prevention Control. |
| PBIT | Profit Before Interest and Taxation. |
| PPP | People Planet Profit (more often PPP = Polluter Pays Principle). |
| RPD | Renewing Product Development. |

## Internet Resources

Austrian Ecodesign platform
http://www.ecodesign.at

Ecodesign, France
http://www.ecodesign.fr

Ecological Design Institute
http://www.ecodesign.org/edi/

Philips – Ecodesign
http://www.semiconductors.philips.com/profile/sustainability/environment/ecodesign/

The Ecodesign Foundation (EDF), Sydney, Australia
http://www.edf.edu.au

United Nations Environment Programme (UNEP) and Ecodesign
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

European Commission – The IPPC Directive
http://ec.europa.eu/comm/environment/ippc/

European Commission – The Integrated Product Policy (IPP) Directive
http://ec.europa.eu/comm/environment/ipp/

# 2 Resource Flow and Product Design

## 2.1 The Environmental Dilemma of Resource Flows

### 2.1.1 Resource Use and Product Design

Resources are used to produce products, and all product design processes have to develop and deal with a resource policy. To accomplish an ecodesign a clear understanding of environmental consequences of the resource use is necessary. In subsequent chapters in the book we will discuss in some detail how to deal with material choice, product function and product recycling, all of them important for resource flow. In this chapter we will describe why resource flow constitutes a dilemma, which designers will have to deal with.

### 2.1.2 Categories of Resources

There are different ways to group resources. A commonly used one distinguishes the following seven categories [Hillary and Jolly, 2001]. These all have their specific properties from the point of view of the environment.

1. *Bulk material* is material extracted from the *pedosphere*, the uppermost layer of the ground. Bulk material is abundant. The problem with its use is not the amount but the fact that the ground from where it is extracted is disturbed or destroyed.

2. *Macro nutrients* – nitrogen, phosphorus and calcium – are used in large quantities in agriculture but also in a long series of chemical compounds, such as phosphorous in detergents, and nitrogen in various plastics. Nitrogen compounds are mostly produced by reduction of atmospheric nitrogen into ammonia, a process that requires large amounts of energy, while phosphorous is mined. Nitrogen is thus available in practically unlimited quantities, while phosphorus is a non-renewable resource. The present layers are large, however, and will last more than 200 years, at the present rate of extraction.

3. *Minerals* are compounds extracted from the *lithosphere*, the bedrock. They are used to produce metals. Metals can be characterised according to their technical use. Iron is in a class by itself. Metals used mainly as alloys with iron, called ferro-alloy metals, include chromium, nickel, titanium, vanadium and magnesium. The traditional non-ferrous metals are aluminium, copper, lead, zinc, tin and mercury. Metals are of course by definition non-renewable. Iron and aluminium, how-

**In this Chapter**

ever, which are very abundant in the surface of the planet, will not be depleted by present levels of use. All other metals are being mined at a rate of about one order of magnitude larger than the natural weathering. Some rare earth metals are already almost depleted from known sources [Karlsson, 1997].

4. *Stored energy resources* include lignite, black coal, oil and gas. Coal, oil and gas, which were formed hundreds of millions of years ago, are *fossil*. The fossil fuels are *non-renewable*. They are presently used at a rate that is millions of times larger than their eventual renewal. Peat is formed on the time scale of thousands of years. Some consider peat fossil since it is not at all reformed at the rate we might use it, while others do not include peat in the group of fossil fuels.

5. *Flowing energy* **resources** refer to resources which depend on the sun. *Direct* solar energy resources include solar heat, solar electricity and photosynthesis. *Indirect* solar energy – sometimes referred to as *streaming* resources – includes waves, wind or flowing water. These are used in wave energy (which is technically difficult), wind energy and hydropower.

6. *Environmental resources* are what we and all life forms depend on every day and minute for our lives, the air we breathe, the water we drink and the soil we walk on. This is also referred to as the *ecosphere* or *biosphere* of the planet. The environmental resources provide what is called *ecological services*. This refers to the support of life forms, and the absorption of emissions from these processes.

7. *Biotic resources* are biomass to provide food and fibre for our livelihood, and a long series of other products, such as pharmaceutical substances, landscape. These resources are *renewable*, but, of course, limited. The production rate of the biotic resources are referred to as the *carrying capacity* of the area considered.

### 2.1.3 The Large Size of the Resource Flow

The resource flow on our planet is very large (see further the discussion in the Introduction). Material Flows Analyses, MFA, carried out in several countries in Western Europe show that flow of solid material is about 60-80 tonnes per capita and year (see Introduction, Figure 6). The figure is slightly smaller in e.g. Poland (about 50 tonnes) but much larger in the USA (about 80 tonnes). Materials in the largest amounts are bulk material (for building purposes), fossil fuel (energy purposes) and macro nutrients (mostly agriculture).

**Box 2.1 Categories of Resources**

1. Bulk materials such as stone, sand and gravel
2. Macro nutrients: nitrogen, phosphorous, calcium, and sulphur
3. Mineral resources, metals
4. Stored energy resources, fossil fuels
5. Flowing energy resources, solar energy, hydropower etc.
6. Environmental resources, soil, water and air
7. Biotic resources, biodiversity and sylvi-cultural products (wood, fish, etc.)

An estimate of the material flows on the planet as a whole [Schmidt-Bleek, 1994; The Global Footprint Network, 2005] indicates that it is about 35% more than the carrying capacity. This over-use of the resources corresponds to the use of fossil fuels, deforestation, over-fishing and so on. Resource use has increased during the entire history of mankind, but was far below the available resources up to about 100 years ago. During the 20th century resource use increased about 20 fold in many categories, for example, energy, and much more in some, for example, macro nutrients [MacNeill, 2000]. The carrying capacity of the planet was passed probably around 1980.

In 1995 the American environmentalists A.B. and L.H. Lovins together with E.U. Weizäcker, Direcor of the Wuppertal Institute, published the book *Factor Four: Double Welfare – Half Resource Use*. The title indicates that we need to reduce resource use by a factor of two, but if we can use the resources twice as efficiently we do not need to lose any welfare.


**Figure 2.1 Oil society.** *Today fossil fuel – coal, oil and gas – dominate both the energy market and the chemical industry. World-wide, fossils account for some 80% of energy provisions. In the Baltic Sea region, the eastern countries, e.g. Poland and Russia, have an even larger dependency on fossils, while Sweden is on a level of 40% fossil dependency. For product design it is important to produce products that are energy efficient and when possible use renewable energy sources. Also in manufacturing petrochemical processes, the use of oil as raw material dominates. Here the challenge is to find alternatives, building on so-called green or sustainable chemistry. The oil tankers on the Baltic Sea, increasing in number drastically, also constitute a threat of a major accident that would be a disaster for marine ecosystems. Photo: Norsk Hydro ASA.*

Factor four was meant to be a global policy. But resource use is not equally distributed over the planet. The industrial countries use far more resources per capita than developing countries. One might conclude that one essential task for our industries is to reduce resource use drastically. In fact it is possible to estimate that if resource use in the world as a whole were to decrease by a factor of two and resources were to be used equally in all countries, the industrial countries would have to reduce by a factor of close to ten. This is due to the fact that industrialised countries use 80% of the resources but have only 20% of the global population. The concept of *Factor 10*, meaning that material flows should decrease by a factor of ten, may seem extreme, and of course it builds on a simplified calculus [Spangenberg and Schmidt-Bleek, 1997] but it has been accepted as a policy goal in several countries and in the European Union.

### Box 2.2 Environmental Consequences of Resource Flows

- Global warming caused by accumulation of carbon dioxide from fossil fuel combustion in the atmosphere
- Eutrophication due to accumulation of nitrogen and phosphorous from agriculture in water bodies
- Acidification of forests and lakes due emission of sulphur oxides from combustion of fossil fuels
- Toxic effects of metals accumulating in the environment, e.g. mercury and lead
- Toxic effects of man-made substances accumulating in the environment, such as PCB

### 2.1.4 The Environmental Consequences of Large Resource Flows

Material flows should decrease not only because resources are over-used but because resource flows as such lead to severe environmental problems. Most material flows in industrial countries are *linear*. The material flows directly, so to speak, from the sources to the waste heap. The material set in motion accumulates in the environment and cause problems. The most severe of these include:

- Global warming caused by accumulation of carbon dioxide from fossil fuel combustion in the atmosphere.
- Eutrophication due to accumulation of nitrogen and phosphorous from agriculture in water bodies.
- Acidification of forests and lakes due emission of sulphur oxides from combustion of fossil fuels.
- Toxic effects of metals accumulating in the environment, e.g. mercury and lead.
- Toxic effects of man-made substances accumulating in the environment, such as PCB.

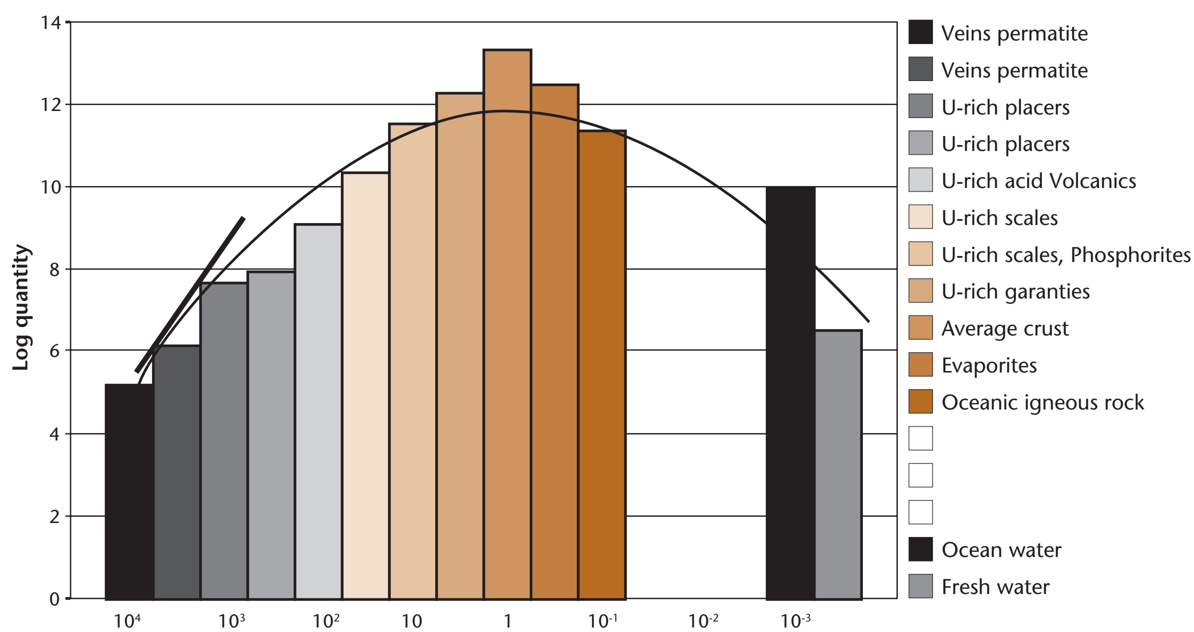



**Figure 2.2 Distribution of uranium over the world's crust.** *The grade on the horizontal axis ranges from 50,000 to 0.0005 parts per million; every two bars is one order of magnitude [Deffeyes, 1964]. In the same report Deffeyes also presents data on the distribution of other resources.*

## Box 2.3 Materials Management Strategies for Improved Material Flows

### I. Reducing the flow – use less material for a service

1. *Use the material more efficiently.* By raising the transmission voltage in a copper wire it is possible to reduce the amount of copper needed to transmit a certain current.
2. *Increase the quality of the material.* By increasing the strength of a metal, e.g. by using an alloy, less material can be used for the same purpose. It has been estimated that the Eiffel Tower in Paris today could be built with one seventh of the steel content it actually has.
3. *Miniaturization – use smaller equipment.* By making equipment smaller, less material is used. Computers, now based on miniaturized electronic components, such as silicon chips, provide a dramatic example. A much smaller computer serves the same functions as a large machine earlier.
4. *Multi-functionality – Let the equipment serve several purposes.* Multi-functional use of products offers another opportunity for reducing the need for materials for a given function. For example, a roof-mounted solar collector can also function as roofing.

### II. Slowing down the flow – make the material last longer

5. *Improve the quality to make the equipment last longer.* By making the products last longer, for example, with increased quality, the same amount of materials can provide services for a longer period, therefore reducing the amount of materials for a given service.
6. *Protect the material in the equipment better.* Materials can be protected from wear or corrosion. Modern cars last much longer than those from before due to better protection of the surface.
7. *Better maintenance.* By regular maintenance and by using equipment that can be maintained properly, the equipment or material can be used longer.
8. *Reparability – Make the equipment easier to repair.* Reparability, for example, through a modular construction of equipment, will increase the longevity of the materials used.

### III. Closing the flow – use the material again

9. *Reuse the goods themselves.* Most goods or equipment are of course used more than once. In some instances a proper strategy is required to make this happen, as with glass bottles that may be refilled.
10. *Recycle materials in production processes.* Many different strategies are applicable in the industrial production process to reduce material intensity. This is part of waste management strategies. Thus manufacturing waste can fed back into earlier material-processing steps, as when for example copper scrap in the manufacturing of copper wires is fed back into the process.
11. *Recycle materials in consumer goods – true recycling.* Materials in consumer goods may be recycled. This is particularly important for materials that are toxic, such as heavy metals, or materials that are expensive to produce, such as aluminium. Important cases are thus recycling of the metal in aluminium cans and the lead in lead-acid batteries. Recycling of the material to the same use once again is true recycling.
12. *Cascading or down-cycling of materials.* In many cases there is an inevitable loss of quality in materials when they are used. However they may be suitable for a different use requiring less quality. This is down-cycling or cascading. The typical example is paper where the fibres in the paper itself go through a wearing process, which limits the use to about six cycles. The chain might start with high quality paper going over newspaper to cardboard paper. The chain or spiral ends when the material is used for energy production in combustion.

### IV. Substitute the flow – Use a different, less harmful, material

13. *Substitute a less harmful material for a harmful one.* Transmaterilization means that one material is exchanged for another. An important aspect is when a hazardous material is replaced by a less harmful one. The exchange of mercury in a number of applications, from barometers to tooth repair, belongs to this category as does the exchange of many solvents used for painting.
14. *Substitute a less scarce material for a scarce one.* Sometimes it is important to find a less scarce material for a particular use. Replacing copper wires in telephone connections with fiberoptic cables is one example.
15. *Substitute a renewable material for a non-renewable one.* The non-renewable materials will in the end necessarily be exchanged for renewable ones. An important example is when fossil fuels are exchanged for renewable fuels, such as biomass. An important case is the replacement of petrol in cars with alcohol from biomass.

*Source: Reproduced from [Karlsson, S. 1997].*

As a rule the flow of non-renewable resources causes environmental problems long before they are depleted at the source. The environment is not able to handle large amounts of a substance that is not part of the normal set-up. As the resource flow continues, it leads to an accumulation of the substance, and sooner or later it will become detrimental to the environment. The large anthropogenic material flows of resources are not similar to the natural flows. Ecosystems, as a rule, recycle resources and all material are used for new purposes.

### 2.1.5 Sustainability Principles for Improving Resource Management

Good material management should obey a few simple rules, included in the so-called *physical principles for sustainability* [Holmberg et al., 1994], adopted as the systems conditions in the Natural Step Foundation:

- Do not cause the accumulation of material from the lithosphere in the ecosphere. (Material from the lithosphere (bedrock) includes metals and fossil fuels.)
- Do not cause the accumulation of man-made substances in the ecosphere.
- Do not cause the systematic destruction of the productive capacity of the environment (e.g. by ongoing extraction of material and thus depleted land use, as in erosion).

To live up to the basic rules, materials need to be recovered and reused rather than ending up in the environment. *Recycling* is thus a basic strategy. *Dematerialisation*, that is, slimming the material flow, is also basic. Non-renewable materials should not be used unless it is possible to ascertain that they are recycled. Thus recycling will make it possible to continue to use metals although they are non-renewable. However fossil fuels will not be acceptable in the longer term since it is not possible to recycle them, except to a limited degree.

Today material flows and energy flows are mostly coupled. We thus see the need for a different energy policy that says that energy flows need to be *de-carbonised*, uncoupled from the carbon flows, the use of fossils.

Total material flows are in practice coupled to toxic material flows, that is, flows of toxic materials are roughly proportional to material flows. Here, too, there is a need for a different materials management policy, one that avoids toxic material.

Resource use will have to be reduced, and some resources abandoned all together. A summary of materials management strategies supporting this goal are found in Box 2.3.

## 2.2 Resource Availability

### 2.2.1 Minerals

In the geo-statistical model for minerals, it is generally accepted that the distribution of concentrations of mineral resources is log-normal if we plot quantities against grade. This phenomenon has been described, for single deposits, as Laski's law. There is wide agreement amongst resource geologists that log-normal ore grade distribution is a reasonable approximation also for the world-wide ore occurrences of a large share of minerals. Although real proof for this relation is not easy

**Table 2.1 Fossil fuels sub categories** *[Eco-indicator 99, 1999].*

| Category | Sub-Category | Remarks |
|---|---|---|
| 1. Oil | 1.1 Conventional Oil | 1.1.1 All currently produced oil, which easily flows out of large wells |
| | 1.2 Unconventional Oil | 1.2.1 Tar sands |
| | | 1.2.2 Shale |
| | | 1.2.3 Secondary oil (produced from existing wells with steam injection |
| | | 1.2.4 Tertiary oil (oil from infill drilling, reaching pockets that were originally bypassed) |
| 2. Gas | 2.1 Conventional Gas | 2.1.1 Wet gas, associated with an oil accumulation |
| | | 2.1.2 Dry gas, unrelated to oil fields |
| | 2.2 Unconventional Gas | 2.2.1 Natural gas liquids (condensed gas) |
| | | 2.2.2 Gas from coal-beds |
| | | 2.2.3 Gas from tight reservoirs |
| | | 2.2.4 Others, like mantle gas from deep in the earth crust |
| | | 2.2.5 Hydrates: gas in ice-like solid concentrations in oceans and polar regions |
| 3. Coal | 3.1 Conventional Coal | 3.1.1 Open pit mining (Anthracite or Lignite) |
| | | 3.1.2 Underground mining |

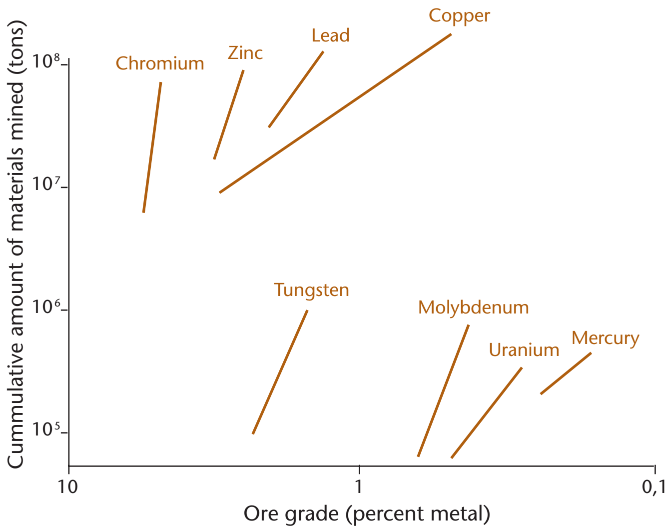



**Figure 2.3 Slope of availability against grade for metals.** *If the slope is steep, much more resources are found as a lower grade ores are mined [Chapman and Roberts, 1983].*

to provide, an illustrative example for the case of uranium is available from Deffeyes [Deffeyes, 1964].

Deffeyes has determined the average concentrations of uranium in different types of rock and in water. This data, combined with data on the world distribution of rock types has been combined (Figure 2.2). The grade varies in this graph from 50,000 to 0.0005 parts per million. From the graph you can see that the size of the resource stock is completely dependent on the grade, which we are willing to mine.

Chapman and Roberts refer to the work of Deffeyes and base their analysis of the seriousness of mineral extraction on data from Deffeyes [Chapman and Roberts, 1983]. Figure 2.3 (taken from Chapman) shows the relation between resource availability and the concentrations. If the slope is steep, the resource availability increases sharply as the concentration decreases slowly. The quality of minerals with a steep slope decreases relatively slowly when extraction continues.

## 2.2.2 Fossil Fuels

For fossil fuels the term “concentration” is not a very good indicator for the resource quality. The processes that have produced and distributed the fossil fuels are quite different from the processes that have caused the log-normal distribution in the earth crust. This means that the log-normal distribution of resource concentration is not directly applicable to fossil fuels.

Basically three types of fossil fuels can be distinguished. These three types can be differentiated in a number of sub categories (Table 2.1). The brief overview demonstrates that apart from the conventional sources there are several alternative (unconventional) sources for oil and gas. As in the case of minerals, until now only conventional sources are used, as these can be extracted with the least effort.

Quite unlike the case of minerals, the effort of exploiting a resource does not decrease gradually when the resource is extracted. As long as sufficient conventional oil can be found, the effort to extract the resource does not increase significantly, as long as the oil keeps flowing.

Only when conventional resources become really scarce will mankind have to start to explore unconventional resources. In this case the effort to extract the resource does increase. In the example of oil this could mean that additional drilling and pumping or even steam injection is needed.

So instead of a continuous decrease of the resource quality, you can observe a stepwise resource decrease, while between these steps the effort to extract is basically constant.

Conventional oil (and gas) has been formed during certain distinct periods in distinct places. For instance the huge oil resources in the Middle East, the North Sea and Siberia were formed in

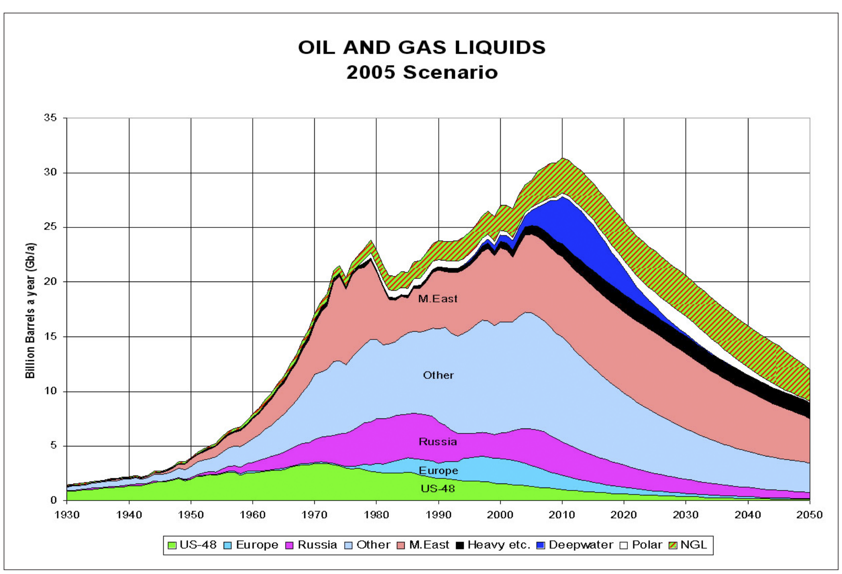



**Figure 2.4 The oil depletion curve.** *Oil availability over time is shown for a number of regions in the world. It is seen that e.g. the American oil is practically used up and the North Sea resources is declining. Oil is a finite resource. Peak oil refers to the time when global oil production is at its maximum. It is presently expected to occur 2008-2010. The production is then predicted to come to a very low level at about 2040. Natural gas production and consumption is seen to follow a similar pattern, with some ten years delay. [http://www.peakoil.net]*

the late Jurassic, some 150 million years ago. Another period was the Cretaceous, some 90 million years ago, which was responsible for the formation of oil in northern South America. The oil in North America dates from the Permian, some 230 million years ago. Oil and gas usually formed in shallow seas or lakes in areas around the tropics. Stagnant sink holes and lagoons were perfect places to preserve organic material.

Unlike the formation of minerals, the formation of fossil resources can be deducted from our knowledge of the plate tectonics, the climate changes and other processes that occurred the last half billion years of the earth's history. In global terms the bulk of oil and gas occurs in a geological "province" called the Tethys: a zone of rifting between the southern and the northern continents, of which the Middle East, the Mediterranean and Mexico are remnants.

Detailed geological mapping has revealed where suitable formations, under which oil could have been trapped, are located. Because of this understanding, one may conclude that the world has now been extensively explored, that all large oil resources have been found and that the scope for finding an entirely new field of any size is now greatly reduced, if not entirely removed [Campbell, 1998] (Figure 2.4).

From this and the present rate of extraction it is straightforward to predict the rate of depletion. The data at present (2005) (See Internet Resources, *Association for the Study of Peak Oil and Gas*) predicts that resource extraction will culminate in 2008-2010 and oil resources will be mostly depleted by 2040. The comparisons between rate of extraction and rate of production (Figure 2.5) indicate that the price of oil will increase substantially in the near future.

The resource availability for coal is much higher than for conventional oil or gas. The proven resources should be sufficient for about 200 to 300 years, if the present extraction rate is sustained, and if no major discoveries are made.

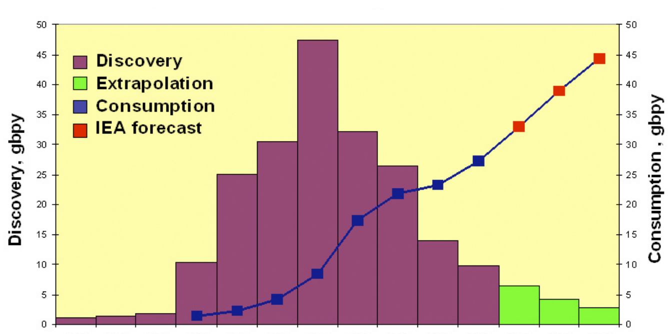



**Figure 2.5 Rate of production vs the rate of discovery.** *Global oil discoveries peaked in the 1960s and are rapidly declining as oil becomes harder to find. Today there is a growing gap between new oil discoveries and production (gbpy = Gigabarrels per year). [http://www.peakoil.net]*

## 2.3 Resource Depletion

### 2.3.1 Problems Connected with Resource Depletion

In general there are three important problems when resource depletion is described:

*The stock size* (or, in the case of flow resources, the supply rate) is very much dependent on *the effort* mankind is prepared to make to get a resource. To some extent, most *resources can be substituted* by other resources. Even between the categories of resources, substitution is often possible (for example, replacing steel with wood). Because of this it is difficult to determine the essential property of a resource and, therefore, why depletion of such a resource would be a problem. The essential property determines the primary function the resource has to mankind. Usually this is an economic function.

Some resources are not really used in the sense that they disappear after use. In principle all minerals stay on earth, and can theoretically be recycled. This is not the case for fossil fuels. Although they do not disappear, their useful essential property is lost.

Bulk resources are abundantly available for the foreseeable future in most regions. In many countries the real problem is the land conversion problem. For instance, in the Netherlands the extraction of lime and gravel will stop completely within a few years, while the proven reserves for lime would at least cover the present consumption rate for 300 years.

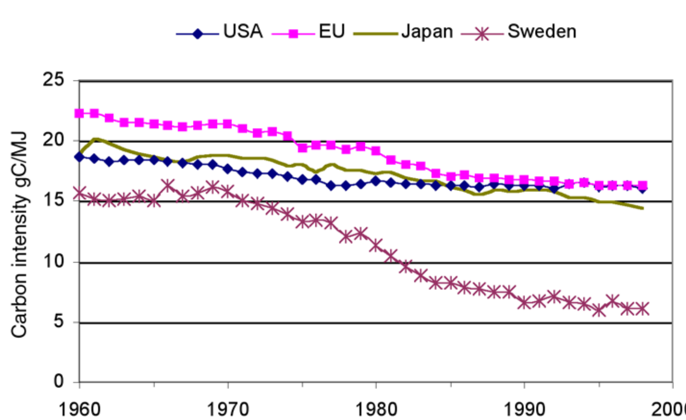



**Figure 2.6 Carbon content of energy.** *The graphs show carbon emissions divided by primary energy supply in the EU, Japan, Sweden and the United States over a 40-year period. The graphs show a slow decarbonisation of energy or decoupling of energy from carbon flows. The dramatic drop for Sweden during 1970-1990 is mostly due to the expansion of nuclear energy. [International Energy Agency, IEA, 2001 and Marland et al., 2001 cited in Azar et al., 2002].*

### 2.3.2 Damage to Resources Caused by Depletion – Minerals and Fossil Fuels

If the resource quality decreases, economic factors and environmental burdens associated with mining low grade ores will become the real problem. The latter includes the land use for the mining operation and the amount of energy to extract the resource from the low-grade ore. The availability of land and energy could thus form the real limitations, and land-use and energy use will probably be the most important factors. This is the basis for the proposal by Blonk [Blonk et al., 1997]. When we look at alternative energy resources, another additional option is to translate increased energy consumption into increased future land use, as most non-fossil energy sources use a relatively large area. Ros proposes some land-use values for the most important solar- and wind-based technologies [Ros, 1993].

*Surplus energy* is defined as the difference between the energy needed to extract a resource now and at some point in the future. The only purpose of the surplus energy concept is to have a relative measure of the damage the depletion of a mineral or fossil resources causes.

The relation between energy use and the lowering of ore grades for the most common minerals has been analysed by Chapman and Roberts [Chapman and Roberts, 1983]. Chapman states there are three effects:

- The amount of energy needed to change the chemical bonds in which the mineral is found is by definition constant. It is not possible to reduce this energy requirement by efficiency improvements or technological developments.
- The energy requirements needed to extract, grind and purify an ore goes up as the grade goes down.
- The energy requirements needed to extract, grind and purify an ore goes down with efficiency increases and technological developments.

Chapman shows convincingly that until now the third mechanism is stronger than the second. This means that although the grade of all ores decreases, historically the energy requirements also decrease.

Chapman shows that this trend will continue many decades from now. In the case of copper you can extract about 100 times more than mankind has done so far before the actual energy requirements get higher than the present values. For most other metals the situation is even better.

Future efficiency increases are not taken into account in existing life cycle assessments, LCA. This is consistent with the other damage models. For instance you do not take into account the possibility that the treatment of cancer will be improved, when you look at long term exposure. It is also common practice in LCA not to take possible remediation technologies into account (this is also widely discussed in Chapter 12).

With the descriptions of the typical characteristics of the fossil resources in the resource analysis, and with the data on the increased extraction energy for non-conventional resources, you can begin to construct the model for the surplus energy. However, in the case of fossil fuels you need to discuss three specific problems:

- The discontinuous or stepwise character of the quality decrease for fossil resources.
- The possibility of substitution between fossil resources.
- The possibility of outphasing fossils and substitute with renewables.

In the case of minerals, you could assume that the decrease of mineral resource concentrations is almost a straight and continuous line. In the case of oil and gas extraction, you are faced with the problem that the extraction will cause rather abrupt steps in the resource quality, when the marginal production of oil and gas switches from conventional to unconventional resources.

## 2.4 Perspectives on the Resource Flows Dilemma

### 2.4.1 Resource Substitution

In mineral resource analysis substitution between resources is not taken into account, as the possibilities for substitution are dependent on future changes in demand and technology development [This section is based on Hillary and Jolly, 2001]. In the case of fossil fuels the possibility for substitution is much more logical to assume, as all fossil fuels share the same essential property, that is, that they supply energy. It is even possible to produce an oil replacement from coal. This is in contrast with the case of minerals. You cannot say that mercury and iron have the same essential properties.

For full substitution between fossil fuels, you will have to assume a future fuel mix. It is fair to assume that about 50% of the fuel will be a liquid, as such fuels are easy to handle and transport. Chapman shows that coal liquefaction is very energy-intensive; about 50% of the energy produced is lost. He therefore argues that it is not likely that in a future energy mix coal will be converted on a large scale. As a result, coal will have a share of less than 50%. Therefore he proposes to assume an energy mix of 50% shale, and 50% coal. He also assumes that coal mining will be mainly practised in a mode that has the same approximate energy requirements as underground mining of anthracite or mining of lignite.

The fossil fuels supply us with energy, but there are many other sources of energy. Substitution of oil and other fossils for e.g. biomass is thus standard in many instances, as well as substitution of using of fossils with other energy producing technologies. These include nuclear power, hydropower and more recently wind power. These alternatives will be further discussed below.

About 90-95% of oil is used for energy purposes, and 5-10% in the manufacturing of various materials, mostly plastics. It will be more difficult to substitute for oil in petrochemical plants. This will not be as urgent as finding substitutions for use of fossils for energy purposes. More processes are however found that uses materials of biological origins, such as cellulose or starch, for such purposes. It is for example possible to use biomass to produce methanol or ethanol which in turn can be processed into various plastics.

### 2.4.2 Three Perspectives – Individualists, Egalitarians and Hierarchists

Much of the environmental perspective is built up from a kind of (environmental) pressure and exerted by the social environment via the market: consumers make demands about products and production processes. But, through their social contacts, managers and employees are also asked about safety at their place of work and the responsibility that the company takes for nature and the environment. The "environment", in the sense of well-being of nature, also has a direct influence on personnel. Perceptible damage to the immediate environment serves as an incentive for improvement. This, placed in relation with resource depletion, is a typical subject in which cultural perspectives can lead to different approaches. Here we will distinguish three different attitudes, called Individualists, Egalitarians and Hierarchists.

**Individualists** do not consider fossil fuel resources a problem, and they advocate a business as usual attitude. Furthermore, individualists would argue that, based on experience (especially after the so-called oil crisis), fossil fuel depletion is not really an issue. Furthermore, as the long-term perspective is not relevant to them, they would not give much weight to future problems that might occur.

**Egalitarians** have a different view of needs and resources. Egalitarians assume resources cannot be managed, while needs can. For them it is logical to assume substitution, as they are not really interested in the differences between resources; fossil fuels all belong to the same "unmanageable" group of resources. For them it is important to implement a need-reducing strategy for fossil fuels as a group, for instance, by stimulating alternative energy sources.

**Hierarchists** assume needs cannot be managed, but resources can. For them it is important to look carefully at the differences between the resources in order to develop management strategies.

### Box 2.4 Energy Policy in Europe

Energy policy in Europe today has three main sets of drivers:

- Increased competition to bring down costs and make industry more competitive.
- Security of supply to keep the lights on at times of peak demand and to avoid overdependence on any one fuel.
- Protecting the environment from harmful emissions.

Renewable energy offers considerable prospects as it can reduce dependence on exhaustible fossil fuel reserves and offers emission-free energy. The shallow sections of the North Sea and Baltic Sea offer possibilities for offshore wind generation, and the coastline of our western shores are among the richest potential sources of wave energy. Waste to energy, biomass (burning cropped materials to recover energy) and solar energy either passively in building design or for direct generation of energy could have a role to play. So what barriers are preventing the rapid deployment of renewable energy in a liberalised market?

The principle issue is cost. While renewable energy prices have tumbled, in the vast majority of instances they still fail to compete with conventional power generation from coal, nuclear and natural gas. Some argue that they should be given a guaranteed price premium, as they are in certain parts of Europe. Others argue that if the cost of environmental damage were included in the cost of fossil-fired generation (the externality cost), then renewables would be cost competitive and hence seek such mechanisms as a carbon tax to balance up the economics in favour of renewables.

The sale of "green energy" is likely to be encouraged, using certification schemes such as that recently developed for industry by the Energy Savings Trust, but customers will have to be found and retained. It seems probable that all energy suppliers operating in the new competitive energy markets will have to secure a portion of their energy from renewable resources, but they will need to keep costs down. The planning system may well be streamlined, but public acceptance will still require hard work.

*Source:*
*http://europa.eu.int/scadplus/leg/en/lvb/l27014c.htm*

*In early 2006 the energy policy of the European Union is in a phase of strong development and the present policy (from 2004) is likely to soon be revised.*

**Table 2.2 Archetypes of current fuels** *[Eco-indicator 99, 1999].*

| | Future fuels | | |
|---|---|---|---|
| **Current fuel** | **Hierarchists** | **Egalitarians** | **Individualists** |
| Conventional natural gas | oil shale | coal-shale mix | conventional gas |
| Conventional oil | oil shale | coal-shale mix | conventional oil |
| Hard coal, open pit mining | brown coal | coal-shale mix | hard coal, open pit |
| Crude oil, secondary extraction | brown coal | coal-shale mix | oil, secondary |
| Hard coal, underground mining | brown coal | coal-shale mix | hard coal, underground |
| Brown coal, open pit mining | brown coal | coal-shale mix | brown coal, open pit |
| Crude oil, tertiary extraction | oil shale | coal-shale mix | oil, tertiary |
| Crude oil from shale | oil shale | oil shale | oil shale |
| Crude oil from tar sand | tar sand | tar sand | tar sand |

## Box 2.5 Individualists, Egalitarians, Hierarchists – Three Ways to Perceive the World

How to perceive and act on environmental risks depends on your world view. An often-used model is derived from a *cultural theory of risk* published by Michael Thompson in 1990. He categorised people in five main groupings: Individualists, Egalitarians, Hierarchists, Fatalists, and Hermits. Hermits and fatalists are at the fringe of society and certainly not numerous, but the other three groups are often seen as major perspectives on environment and world development. This categorisation has been tested in focus groups in risks analysis and seems to describe reality fairly well.

Alan AtKisson in his *Believing Cassandra* [1999] describes what he calls "the three kinds of active players in the game called the World" as follows:

*Individualists* are believers in the ingenuity of human beings and the resilience of Nature. Nature is there for us to use, there is plenty of it to go around, we can't do much to hurt it, and if we do, technology will fix the problem. Any risk to nature is worthwhile, because the rewards – freedom and prosperity for all – are too great to pass up. Human creativity, hard work and the free market will carry us over any hurdles and up to unimaginable heights.

*Egalitarians* hold quite the opposite view. Nature is already buckling under the pressure of humanity, and must be protected. No further risks should be taken or we will lose our planetary life-support system. We should guide people toward a more equitable, less environmentally damaging, lifestyle.

*Hierarchists* occupy a kind of middle ground, but with a twist. They believe in partnership and control. Stability is their core value. They will accept a certain amount of risk to Nature in pursuit of broader social goals. But they also think that human nature is basically problematic and that only by a solid system of clear rules, regulations and financial incentives can you prevent people from pushing Nature – or the World – too far.

Paul Harrison, a clear Egalitarian, in his *The Third Revolution: Environment, Population and a Sustainable World* [1992], writes "Human history is the history of increasing numbers, increasing consumption and increasingly invasive and disruptive technology." AtKisson suggests that we should compare this with an Individualist's view: "Human history is the story of triumph over the terrors of nature, increasing mastery over the earth and its resources, and increasingly brilliant technological achievement." and a Hierarchist's: "human history is the record of a steadily rising population, meeting its needs through careful stewardship of both people and resources, and pursuing least-cost technological solutions to the inevitable problems encountered along the way, with the hope of effective government and justly administered laws."

It is clear that today the world is run by Individualists pointing to Economic Growth as the remedy to any problem; it is part of most commercial cultures. The three perspectives are used both when it comes to how we see the use of natural resources (this chapter) and the seriousness of environmental impacts (used in the Eco-indicator 99 weighting, see Chapter 6).

*LR*

Table 2.2 shows the assumed fossil fuels that will replace the current fuels for the three archetypes. The surplus energy calculation is based on this table. The coal-shale mix is the assumed future energy mix for the egalitarian perspective.

Although egalitarians are very much in favour of eliminating the need for fossil resources, you cannot assume that this will happen in their perspective. The main reason is that other societal aspects, such as the distribution of wealth, are also important. As long as alternative energy sources are more costly, they would argue that fossil fuels could not be excluded.

Based on these characteristics, you can propose to assume substitution for egalitarians, while for hierarchists you do not assume substitution.

### 2.4.3 A Policy to Reduce Fossil Fuel Use

Fossil fuels are today dominating the world's energy flows. At the same time as the total depletion of fossil fuel use seems remote, the environmental consequences of its use is already serious. Accumulation of carbon dioxide in the atmosphere, due to combustion of coal, oil and gas, is today not only a theoretical cause of global warming. Since the 1990s a dramatic increase in global average temperature is ongoing. The observed temperature increase is in fair agreement with the calculated consequences of actual carbon dioxide accumulation in global climate models. The world leaders have reacted by efforts to reduce the emission of carbon dioxide. This is for all practical purposes identical to reduction of fossil fuel use. A major step was the elaboration of the Kyoto Protocol in 1997. This requires an average reduction of $CO_2$ emissions by 8% by 2008-2012 using 1990 as a base year. The Kyoto protocol was ratified in Febuary 2005, as some 120 states, including Russia, have signed it. However, some large fossil fuel dependent nations, especially USA, have not yet signed. For some time it has been implemented as if it were valid, notably by the European Union.

Policy tools to achieve reduction of carbon dioxide emissions include taxes on emitted $CO_2$, already quite high in some countries, as well as subsidies for changes to other sources of energy. Substantial reductions of fossil fuel use are seen e.g. in Denmark (coal substituted mainly by wind power) Sweden (introduction of nuclear, oil substitution by biomass etc.) and Germany (coal substituted in several ways, wind power and improved efficiency included). In addition since many years a large scale exchange of coal to gas is on-going, which will reduce carbon dioxide emissions per energy unit. Finally increased efficiency of energy use is a main strategy where still much is left to be done, a strategy which is becoming increasingly interesting to industry as the energy prices increase.

#### A Designers Role

Designers have a key role in addressing the material flows dilemma. In creating our future cars, houses, roads, household utensils etc. they decide about the resource flow in our societies to be. Designers should:

- Design products that need less material.
- Design products that are energy-efficient in a life cycle perspective.
- Design products that can be recycled.

The Kyoto protocol includes the introduction of trading of emission rights. This is now becoming an important economic incentive to reduce fossil fuel use, introduced in the European Union in 2004. Units, such as power plants in less developed countries, for which it is less costly to reduce emissions, will sell emission rights to units where fossil fuel substitution or efficiency increase is already far advanced. This will accelerate the march away from fossil fuel dependency.

Some technical solutions to the problems, such as sequestration of carbon dioxide in the underground e.g. in emptied oil wells, are at hand but these probably will play only a minor role in the short term. Thus we should expect that the efforts to implement strategies of substitution of fossil fuel with flowing energy resources will be high in the future.

### 2.4.4 Perfect Recycling – An Alternative to Resource Depletion

If recycling of a resource is perfect, the resource depletion problem is solved. This is an option that should be carefully examined for some metals. Now a perfect recycling, without *any* loss, is not possible in practice, but close to perfect cycles have been realised. Thus recycling of lead in batteries can be done up to 99.9% which already is enough for practical purposes. This is also essential for the purposes of avoiding emissions of lead into the environment due to its toxic properties.

With legal and economic instruments society can support a highly effective recycling. This is interesting for some resources not because they are easily depleted but because it is economically profitable. Thus aluminium and copper both are much less expensive as recycled metal than as virgin ore. The figures for copper are about 1:30. Also iron is cheaper as scrap iron with a factor of about 1:6 (See Internet Resources, *The Wuppertal Institute for Climate and Environment and Energy*). However these values differ in different aspects and depend on many factors. The recovery of these metals are now common practice in many countries, and scrap metal is an object of trade.

## Case Study: Fuel for transport – A Dilemma for Oil Society

### The transport dilemma

Oil is the base for industrial society, and the largest challenge to sustainability. One may have different opinions on how long the existing reserves of oil will last, but everyone agrees that at some point they will be depleted, and therefore oil is not sustainable. While oil consumption is slowly declining in the housing and industrial sectors, it is increasing in the transport sector. To find alternatives to gasoline for cars seems to be a special challenge. Below you will find a few cases where this has been achieved.

**Alternative fuels**

The idea of using fuels other than petrol for cars is over a hundred years old. In 1900 at the World Exhibition in Paris Dr. Rudolf Diesel demonstrated an engine powered by peanut oil. Also at the exhibition an electric car, constructed by Ferdinand Porsche and Jacob Lohner, was demonstrated. In 1925 Henry Ford expressed his opinion, that ethyl alcohol is the fuel of the future:

> *"The fuel of the future is going to come from fruit like that sumach out by the road, or from apples, weeds, sawdust – almost anything… There is fuel in every bit of vegetable matter that can be fermented."*

Finally, in the last decade of the twentieth century, this vision of Henry Ford was gaining momentum, as Toyota and Honda offered commercially produced hybrid cars on the market. Toyota still has a market lead with their Toyota Prius model, which is an electric-hybrid car, but today many other companies offer so-called environmentally friendly cars. They are all low-emission vehicles.

**Hybrid cars**

Several cars on the market are hybrids, using two kinds of fuels/motors. As mentioned the Prius uses both an electric and a combustion motor. The electricity needs to be "green" to make it sustainable, but then it is a good alternative. In a combustion motor only some 18% of the energy in the fuel becomes mechanical energy at the wheels. This figure is several times higher in an electric motor. It is also a zero emission motor.

In hybrids, the most common combination is petrol and ethanol. Ford Focus Flexifuel model is an example. Saab's new 9-5 models called BioPower also use ethanol and petrol. In fact, any conventional motor may be rebuilt/adjusted to use ethanol instead of gasoline. In the European Union today most petrol contains 5% ethanol. This corresponds to some 300,000 cars operating fully on ethanol.

Combustion motors can also run on methane (biogas). Several car models using biogas are available. Volvo, Opel, Volkswagen, Mercedes and Fiat all have models with hybrid engines that combine petrol and biogas/natural gas.

**Figure 2.7 The Lohner-Porsche.** *The electric engine was placed in the front hubs. (The Lohner-Porsche Electric-Car is part of the Exhibitions of the Technisches Museum Wien.)*

**Figure 2.8** *Audi A2 1.2 TDI. Photo: Svenska Volkswagen AB.*

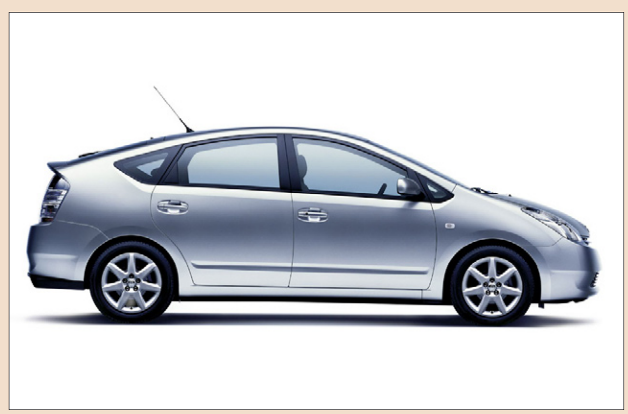


**Figure 2.9** *Toyota Prius. Copyright © 1998-2003 Toyota Motor Marketing Europe ("TMME").*


**Figure 2.10** *The hybrid engine in Toyota Prius.*

**More efficient cars**

Cars in general use much more energy than needed to run. Another option is thus to make cars that are more energy-efficient. A good example in this category is Smart Fortwo Coupé, a small car for two persons that runs on only 2.9 litres/100 km (petrol). Also very efficient is the much bigger model, Audi A2, built of aluminium and with space for four. Audi A2 has a diesel engine, which runs on 2.99 litres/100 km. The Audi has a hybrid engine, which can also use e.g. rapeseed oil (RME) as fuel.

**Transport for the future**

For the future, cars using hydrogen in a combustion motor or hydrogen-powered fuel cells, which in turn run an electric motor, are the most discussed options. An interesting car is BMW 750 hL, a hybrid with the capacity to use both petrol and hydrogen. The technique of hydrogen-powered fuel cells in busses is now being tested in nine European cities in the CUTE (Clean Urban Transport of Europe) EU-project (http://europa.eu.int/comm/energy_transport/en/cut_en.html). In Stockholm there are three hydrogen busses in operation.

**Introduction on the market**

A problem with hybrid cars, for the consumer market, has been the price, which still is slightly higher than for conventional cars. This is changing rapidly with higher oil prices. It is natural that public transport takes the lead for investing in new cars. For short-distance busses and delivery firms, electric, biogas or ethanol is already working in many cities. Their numbers will increase when old vehicles are phased out and replaced. Then we will also have a second-hand market.

Another obstacle is the low number of refilling stations with alternative fuels, which however will change with increased demand. In Sweden the number of refilling stations is increasing rapidly according to a governmental plan (http://www.miljofordon.com).

Magnus Lehman


**Figure 2.11** *Bus with hydrogen-powered fuel cells in front of the fuelling station. Copyright © 2003 HOCHBAHN.*

The use of biomass as energy sources can be seen as another case of recycling. The carbon dioxide emitted as the wood is combusted will later on be reabsorbed during photosynthesis and returned to biomass. As it is harvested for energy purposes the cycle is complete.

### 2.4.5 Social Impact, Quality of Life

All businesses have a choice to make about their attitude to the environment: they can set the trend or they can wait and see. Both attitudes have their benefits and drawbacks. A trendsetter will go against current tendencies or define "a new flow", while the market, his competitors and legislation fail to go along with him. This requires investment and energy. On the other hand, the trendsetter is rewarded: his image is improved, he has a better market potential, a cleaner environmental record and the pleasant feeling of being prepared for what is to come. The trendsetter will see the environment change from being a threat to becoming an opportunity, and even the investment made can yield benefits instead of costs.

A follower adopts a 'me-too-attitude' or reacts only when a certain trend is obvious. This makes it unnecessary to think in terms of scenarios and experimentation. The follower does not regard environmental challanges as an opportunity. After the financial argument ("it costs too much"), uncertainty about environmental issues and forthcoming legislation is one of the most frequently heard arguments for being, and remaining, a follower. This, however, is not ecodesign-specific; uncertainty is a threshold for innovation in general.

## Study Questions

1. Which are the seven principal categories of resources?
2. Describe shortly how the resource flow is working and why it often is a problem
3. Is space a raw material?
4. Which categories of fossil fuels do we have; what are the environmental consequences of their use?
5. Are renewable raw materials exhaustible?
6. In which cases do we face a problem of resource depletion? How can it be solved?
7. How can designers help to reduce the problems connected with resource flows?

## Abbreviations

LCA Life Cycle Assessment *or* Life Cycle Analysis.
MFA Material Flow Analysis.
PCB PolyChlorinated Biphenyl.

## Internet Resources

European Environment Agency
http://www.eea.eu.int/main_html

International Energy Agency, OECD
http://www.iea.org/

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/

European Commission,
Directorate-General for Energy and Transport
http://europa.eu.int/comm/dgs/energy_transport/index_en.html

Overview of European Union energy activities
http://europa.eu.int/pol/ener/overview_en.htm

The Global Footprint Network
http://www.footprintnetwork.org

The Wuppertal Institute for
Climate and Environment and Energy
http://www.wupperinst.org/

Association for the Study of Peak Oil and Gas
http://www.peakoil.net/

The Factor 10 Institute
http://www.factor10-institute.org/seitenges/Factor10.htm

# 3 Strategies for Ecodesign

## 3.1 Designing Ecodesign

### 3.1.1 Product Design Reviews – Tools and Strategies

To develop products designed for the environment is to take into account the environmental impact of certain design decisions. To help designers evaluate such decisions, numerous tools are being developed. Most often so-called *improvement tools* are used. It is clear that most tools are still in their infancy and that much research in the area is needed.

The most comprehensive design tool is *Life Cycle Assessment*, LCA. By the life cycle of a product we mean the stages through which the product passes, from the extraction and processing of its raw material, through production, marketing, transportation and use, to its end management as waste. The environmental impact of a product arises as result of the substantial consumption of resources and energy and the generation of direct or indirect pollutant emissions. It consists of the depletion of natural resources, impact on human health and degradation of environmental quality, in terms of both human and natural surroundings. Later in the book, the state of art and future expectations for Life Cycle Assessment will be discussed in some detail. In this chapter a few more simple improvement tools will be introduced. They will, however, still cover the life cycle of the product in a fairly comprehensive manner.

When reviewing design for environmental improvements, various levels can be identified (Figure 3.2). The most important are:

- Product improvement.
- Product redesign.
- Innovation in the product concept.
- System innovation.

**In this Chapter**

## Box 3.1 Tools for Ecodesign

There are several kinds of ecodesign tools, used for different purposes. Tischner [2001] has distinguished between four such categories: 1) Analytical tools, which indicated strengths and weaknesses of a product; 2) Priority setting tools, selecting the most promising improvements possible; 3) Implementation tools, providing assistance for design, and brainstorming on ecodesign; and 4) Coordination tools, linking the ecodesign to other criteria such as cost benefit analysis, etc.

There is no consensus on what constitutes a tool. The most important feature is of course that it is useful for the designer. A few of the most important tools are briefly described below [Tischner, 2001].

**LCA Life Cycle Assessment**

An LCA analyses all input and output for all stages of the product life cycle. LCA is a typical analytic tool. It is complicated and time-consuming to use, but provides the most correct and quantitative picture of the environmental impact of a product. Most tools have a "life cycle approach" although they are not complete LCAs.

**MET matrix**

The letters MET stand for materials, energy and toxicity (Table 3.1). A MET matrix shows the material flows, energy use and production of toxic substances for each of the stages of a product life. It is used to:

- Optimise all aspects of the material life cycle of the product, e.g. material use, re-use and recycle possibilities, reducing material and waste use.
- Reduce energy consumption during the whole life cycle, and energy content in the materials.
- Eliminate or reduce toxic (and also non-toxic) emissions.

The MET matrix is used as an analytical and strategic tool.

**PRODUCT SYSTEM LEVEL**

**7. Optimization of end-of-life system**
Reuse of product
Remanufacturing/refurbishing
Recycling of materials
Safer incineration

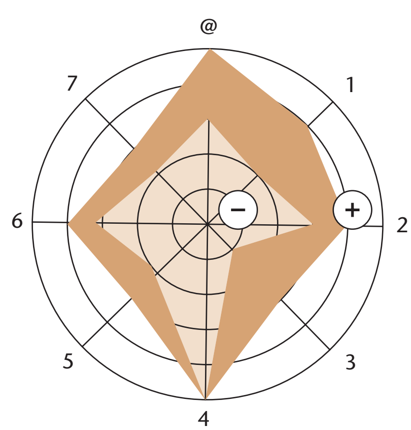
**6. Optimization of initial lifetime**
Reliability and durability
Easier maintenance and repair
Modular product structure
Classic design
Strong product-user relation

**5. Reduction of impact during user**
Lower energy consumption
Cleaner energy source
Fewer consumables needed
Cleaner consumables
No waste of energy/consumables

**PRODUCT STRUCTURE LEVEL**

**4. Optimization of distribution system**
Less/cleaner/reusable packaging
Energy-efficient transport mode
Energy-efficient logistics

**@ New Concept Development***
Dematerialization
Shared use of the product
Integration of functions
Functional optimization
of product (components)




**PRODUCT COMPONENT LEVEL**

**1. Selection of low-impact materials**
Cleaner materials
Renewable materials
Lower energy content materials
Recycled materials
Recyclable materials

**2. Reduction of materials usage**
Reduction in weight
Reduction in (transport) volume

**3. Optimization of production techniques**
Alternative production techniques
Fewer production steps
Lower/cleaner energy consumption
Less production waste
Fewer/cleaner production consumables

Priorities for the new product
Existing product

**Figure 3.1 The ecodesign strategy wheel.** *The Ecodesign strategy wheel shows all the fields of interest in ecodesign, clustered in eight carefully chosen strategies which are pictured on the eight axes of the wheel. The strategies numbered 1-7 are mostly used in eco-redesign. The strategy indicated by the @-sign refers to new product concept developments. It is often used as a stand alone activity, leading to a completely new approach to provide a service as when e-mail replaces ordinary surface post [Hemet and Brezet, 1997; Van Hemel, C.G., 1995].*

**Table 3.1 The MET matrix.** *The letters MET stand for materials, energy and toxicity. A MET matrix shows the material flows, energy use and emission of toxic substances for each of the stages of a product's life. When the matrix has been filled in it gives a useful overview of the environmental impact of a product and pinpoints the most serious ones. It is used for analysis and planning of product redesign. [Te Riele, Zweers, et al., 1994].*

| | M - Materials | E - Energy use | T - Waste/ Toxic emissions |
|---|---|---|---|
| Production and supply of all materials and components | | | |
| Manufacturing: in-house production | | | |
| Distribution | | | |
| Use: operation and servicing | | | |
| End-of-life system: recovery and disposal | | | |

### Materials flows strategies

Materials flows strategies (Box 2.3) covers all aspects of material flows for the product and pinpoints systematically the strategies which can be used for improvements. It is used mostly for analysis and priority setting implementation. It is developed from the Natural Step Foundation's four System Conditions [Holmberg et al., 1994]. Even though these refer to a wider agenda, as a tool for all material flows in an organisation or company, it is useful in ecodesign. The scheme refers to:

- Reducing material flows (use less material).
- Slowing down the flow (make material last longer).
- Closing the flow (that is recycling).
- Substituting the flow (taking out the toxic, non-renewable and scarce materials).

### Spider web diagrams

There are several web diagrams, such as the "spider web diagrams", the "eco-compass" and the "ecodesign strategy wheel" (Figure 3.1). The diagrams allow the user to assess the product against a set of environmental criteria and visualize them. The criteria typically include material use, transport use, energy use, waste produced, toxicity, and longevity. The product is given a value of 0 to 5 (sometimes 1-6 or 1-10) for each criterion, where 0 (or 1) is poor and 5 is excellent. The value is marked on the corresponding axis in the spider web. When the values for the product are connected, we have a picture, that characterises the product. The task for the eco-designer is to propose a modification of the product for which one or several of the criteria have an improved value.

Only relative values are used in the diagram, but it still gives a very vivid qualitative picture of where the improvements are needed, and how the old and new products compare. A spider web is used both for analysis and setting priorities for ecodesign.

### Environmental management systems, EMS

EMS is a very valuable starting point when considering an ecodesign project. Introducing an EMS in a company includes a review and audit which should identify the weak and strong points in a company, including its production. The rationale and objectives for an ecodesign project will then be clear and the management of the company will be included and can define responsibilities and resources needed to do ecodesign. The certification schemes of ISO 14001 and EMAS also provide a valuable standardised way to set priorities, and require that the companies seek improvement wherever it is feasible including the design of its products and services.

### Supply chain management (SCM)

SCM is the incorporation of environmental aspects into the decisions regarding the purchase of materials and parts for the manufacture of a product, and supplier management practices. A review of a product may tell that the major environmental impacts are caused in the supply chain rather than in the company's own manufacturing. SCM will then be a key task in ecodesign [Charter, 2001].

SCM is increasingly important as we come close to the end of a supply chain. Companies selling services typically do not themselves manufacture the products being used in the services, such as detergents for a cleaning company. The ecodesign of the service thus has to include a careful examination of the products they are using, and the choice of the best one, or even forcing the provider to improve the environmental profile of their products. Strong companies such as the large retailers may have a very strong influence on their suppliers, if they are very important customers.

Today we see that companies that are certified according to ISO standards or EMAS ask the suppliers to get certified as well, and may exchange suppliers if they do not comply.

SCM also includes a careful examination of how and from where the suppliers deliver the products. There may be a choice of finding a supplier that is situated closer to reduce transport, or one that is using a better mode of transport.

The first two levels indicate small stepwise improvements of an existing product. The latter two take the function of a specific product as starting point and try to provide that function in a more environmentally-friendly fashion. In product redesign only the former two levels are approached in actuality. To realise a satisfactory global reduction of environmental impact, our attention however must be shifted to the latter two categories. In this chapter eco-redesign, that is levels 1 and 2, will be the main concern. The third level will be briefly discussed under section *3.2 New Concept Development*. The fourth and fifth – system – level will be brought up in Chapter 12. A further description of different design levels with exemplifications is given in Table 3.2.

### 3.1.2 Ecodesign Tools

There are several different tools to use when working with ecodesign. The tools have been developed by various companies or research groups, and used as standard strategies in product development, just as much for business as for environmental reasons. The tools typically address issues of :

- Dematerialisation (decreasing weight and volume).
- Substitution (replacing toxic components, and non-renewables).
- Reducing energy use (both in production and during use).
- Reducing transport needs (e.g finding resources from neighbouring areas).
- Increasing life span of product (e.g increasing repairability).
- Reducing waste generation (e.g. by increasing recycling).

A commonly used tool is the *MET matrix*, where the letters refer to *reduced materials, energy and toxicity*. These three are key words in for example the Brundtland report, which asks for improved effectiveness, efficiency and life-time of products. Another important and commonly used group of tools are the *spider web diagrams* addressing the environmental requirements for a product. The spider web diagrams allow the designer to implement ecodesign in strategic steps. Each one of these is visualized in the diagram and the improvements achievable with a new design can be seen directly. Several of the tools are reviewed in Box 3.1.

Optimisation of the product requires that functional, economic and environmental requirements are all included and balanced. Other tools are used to look at the economic and functional aspects of a re-design project (See Chapter 14). Quite often, however, the result of an ecodesign project is in itself also beneficial for these aspects. One example is the Sony TV, which in the early 1990s was rated badly from an environmental point of view. Not to lose market shares, the management of the company decided to improve. The re-designed TV had eliminated hazardous material, had 52% less plastic, less material over all and was easily disassembled (with only nine screws) to allow 99% recycling. As an additional benefit, it turned out that the new product was 30% cheaper to produce, and could be assembled much faster! Both economy and functionality was improved through the ecodesign process [Design for Environment Guide, 2003].

### 3.1.3 The Ecodesign Strategy Wheel

The *Ecodesign strategy wheel* (Figure 3.1) [Hemel and Brezet, 1997; Van Hemel, C.G. 1995], the perhaps most widely used spider web diagram, is a very useful and comprehensive way of classifying the different strategies. It was developed mainly at Delft University in the Netherlands. It was the basis of a widely used manual published by UNEP [1997], commonly called the *Promise Manual* (full name is *Ecodesign "A promising Approach – to sustainable production and consump-*

**Table 3.2 Levels of eco-redesign of products.** *The table specifies the levels at which the redesign can be made from substitution of resources to the concept level [Månsson, 1993; Holmberg et al., 1994].*

| Level of substitution | Example |
|---|---|
| 1. The raw material level | The same material may be obtained from different raw materials with different environmental characteristics, e.g., hydrocarbons from biota or fossil fuels. |
| 2. The material level | Aluminium can substitute for copper in electrical power transmission. |
| 3. The component level | One type of battery may have better properties than one currently in use. |
| 4. The subsystem level | Electric motors may at one time replace internal combustion engines for cars in local traffic. |
| 5. The system level | Private cars may be largely replaced by trains for medium – and long-distance travelling. |
| 6. The strategic level | Different strategies can lead to the same goal. If the goal is "clean" environment, then there can be a shift in scientific strategy from environmental pathology to societal prophylaxis. |
| 7. The value level | Cultural and individual values decide what strategy to choose. Moreover, if people want sustainable development, this will lead to consequences at all other levels. |

*tion"*). The strategy wheel is a conceptual model, which shows all the fields of interest in ecodesign, clustered in eight carefully chosen strategies which are pictured on the eight axes of the wheel. These are:

Product component level.
1. Selection of low-impact materials.
2. Reduction of materials usage.
3. Optimization of production techniques.

Product structure level.
4. Optimization of distribution system.

Product system level.
5. Reduction of impact during user.
6. Optimization of initial lifetime.
7. Optimization of end-of-life system.

Strategies numbered 1-7 in the wheel concern the improvement of an existing product, often called eco-redesign. The 8th strategy, symbolised by the @-sign, refers to the so-called New Concept Development. A new concept development is not just a better product but a new way to provide the service that the product is there for. The sign is meant to remind us that the Internet is a very powerful alternative to older means of communicating, especially sending by surface mail. It also makes available music, messages and pictures in a new way. Even if one should not forget that also implementation and use of Internet has its environmental impact that needs to be evaluated, it still carries the idea of new strategic thinking.

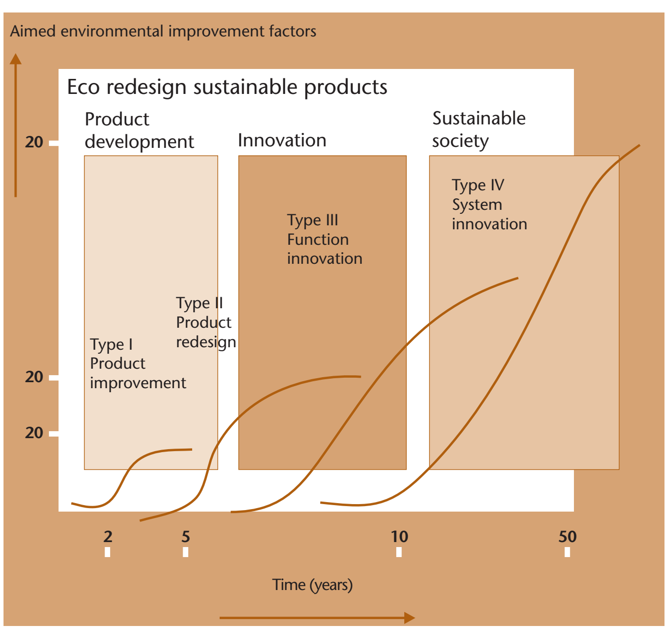



**Figure 3.2 Four types of environmentally friendly product service development** *[Korbijn, 1999].*

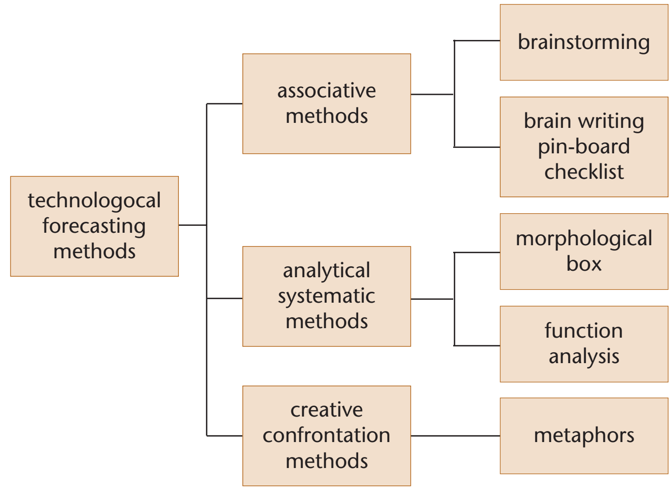



**Figure 3.3 Overview of creativity techniques.** *The figure summarizes a number of techniques used to stimulate creativity in order to come up with new product concepts or developments. The techniques are further described in the manual published by UNEP called "Ecodesign – A promising approach" often referred to as the Promise Manual which in turn is based on the ecodesign strategy wheel [UNEP, 1997].*

One of the best ways to develop and describe your ecodesign strategy is to complete an ecodesign strategy wheel. In the rest of this chapter we will address each item of the wheel in turn. But first a few general comments, mainly based on the *Design for Environment (DfE) Guide* of the Industrial Research Assistance Program of the National Research Council of Canada, in turn based on the original promise manual of the Technical University of Delft.

The strategies in the wheel are numbered according to the life cycle of the product. But this is not necessarily the best sequence when implementing re-design strategies. It will differ between products, between companies and the situation, and no one is "always right". For example when re-designing a photocopier the first concern was to reduce energy consumption during use (strategy 5, reduce impact during use) as it would be very important for the function of the machine. How to select material (strategy 1) or improve recyclability (strategy 7) could wait till the end, since it would not influence function in the same way. However when looking at a package, the material selection (strategy 1) would be the first strategy to deal with, for obvious reasons.

The wheel can be used in many ways and for several purposes. First of all it is a visual representation of the environmental profile of the existing product; it can provoke and inspire improvement options; it is helping you to compare and balance different improvement strategies; it will provide a useful visual comparison between the old and the new product, and for that reason a useful means to communicate your ideas to others, both within an organisation, a company, and to the outside world.

You may also go through each of the stages in product's life cycle and apply all the strategies to each one of them. Thus for resource use, that is the supply chain, all eight strategies can be considered, and so on for all other stages. This will make the design process more challenging, and may in the end lead to a new way to satisfy the customer's demand of the service that the product actually is providing for. It is far more difficult to achieve a good "new concept" than just make a redesign of a product addressing one or a few of the strategies in the wheel.

An outline of a design process is given in Box 3.2

### Box 3.2 Sequencing an Ecodesign Strategy

**Step 1 An idea for the new product**
The starting point may be brain storming for example inspired by the ecodesign strategy wheel. A few key issues for your product will result, for example, how to reduce energy spending during the use phase, how to increase recycling of components, how to manage with less or no packaging. Some of the issues are looked into further through feasibility studies. The results of step 1 should be a short report, a so-called design brief.

**Step 2 A conceptual design**
Next is to look into one or a few of the ideas from step 1 and specify principles or techniques to use for a new design. Referring to the three examples above, these should include an exact description of what principle or technique to use to save energy (insulation, control, new energy source etc), specifying what material to use in some parts to increase recycling, and thirdly how to develop minimal packaging. Step 2 should lead to a report with a short list of specifications for several concepts. One or several of these are then chosen for further work.

**Step 3 A preliminary design**
The third step constitutes the design of the alternatives chosen from step 2. All details of the product should now be specified, including function, choice of materials and, if possible, a quantitative estimate of the environmental improvements of the new design. Step 3 should end with a preliminary design.

**Step 4 A detailed design**
The detailed design should include all data needed for the manufacturing and supply chain of the new product. All materials should be specified. The assembly and disassembly, as well as the repair and maintenance of the product need to be described. The packaging and delivery of the product and finally the take back or recycling at the end-of-life of the product is described.

*Source: National Research Council of Canada, DfE Guide.*

### 3.1.4 Product Design as a Creative Process

Ecodesign makes heavy demands on individual creativity. Some tools used are creativity-stimulating techniques. They attempt to find best answers to the question "How can we conduct a structural search for ideas?" Figure 3.3 gives an overview of the most used creativity techniques which can also be of help in searching for environmental improvements. (A more detailed description on brainstorming is available as a workshop on the accompanying CD.)

## 3.2. New Concept Development

### 3.2.1 Dematerialisation

As mentioned the @-symbol in the ecodesign strategy wheel refers to the strategy that the need for the product may be met in a new way, that is to develop a new concept. A thorough analysis of the need that the product fulfils is necessary to find new concepts. It is very often that this analysis leads to an increased use of shared services, or in general that a service is provided rather than a product. This strategy may be divided into three approaches – dematerialisation, increased shared use and service provision.

Dematerialisation is to replace the physical product with a non-physical one, to reduce the demand of the company for physical products as well as the dependency of the end user on physical products. Obviously such a strategy will reduce costs of material, transport, and energy. Dematerialisation may be that the product itself is becoming smaller and lighter, that the product is replaced with a non-material substitute (as the @-symbol indicates) or that the infrastructure needed is reduced or eliminated. Examples are easy to find (and doing so is a good exercise). Information and communication technologies provide many. Computers are getting smaller and use less electricity. As e-mails substitute for sending surface post the need for a number of physical structures are eliminated. The use of mobile telephones instead of classical ones, leads to a new and completely different and slimmer infrastructure. It is interesting to see how developing countries repeatedly frog-jump several technical generations as they introduce slimmer (and cheaper) technologies.

### 3.2.2 Shared Use of Products

When many individuals make common use of a product without actually owning it the product is normally used more efficiently. Typical examples are common laundry machines, tools for construction or gardening, or equipment for offices such as copiers, and fax machines. The product often becomes the property of an organisation or company, which is managing the shared use. A new organisation may be needed and created.

From the customers' point of view, as products are not used often, it may be advantageous to pay for the individual use rather than the product itself. For the company which owns the product this is a new business opportunity. The company normally can provide the necessary maintenance, technical support etc. better since they know their product in detail, and may even develop the product to their advantage.

The arrangements may take several forms. Companies which lease equipment, for example, for building or gardening or for offices, are common. Associations of house owners sharing equipment are also common. Associations for car pooling are becoming more common, often composed of the owners of one or a few cars. Shared ownership and use of summerhouses, boats, etc is also seen.

### 3.2.3 Service Instead of Products

Sometimes companies find that they can increase profit and add value to a product when selling the service that the product is needed for rather than the product itself. When this happens the company assumes responsibility for maintenance, repair as well as end-of-life, such as recycling. The customer which then buys a service does not have to worry about these things.

One example is Nortel (see *Strategies: Increase shared use* in the Design for Environment Guide) who were buying detergents for their electronic manufacturing to clean their products. At one point this arrangement was changed so that instead the cleaning service was bought from the supplier of the detergent. It turned out that the supplier used the detergent much more efficiently and the whole operation was considerably cheaper. The two – customer and provider – agreed on sharing the benefit. For Nortel this change meant less chemicals and better economy.

Rental services often provide a piece of equipment that is complex or expensive. It may be costly for those in need of the equipment to own and maintain it. The concept of providing a service instead of a product, which today is becoming increasingly common, is making sense. Some truck manufacturers lease rather than sell the trucks to the company which needs transport. They thereby become responsible for maintenance and repair of the car as well as the efficient use of fuel. All these make it more likely that the truck itself will have a longer life, and be more efficiently used and consume less fuel, as it is in the interest of the truck producer. On the other hand, if the company are selling the trucks themselves, it is rather in their interest to sell more trucks.

## 3.3 Choosing Low Impact Materials (Step 1)

The first step in the ecodesign strategy wheel is focused on the impact of materials. It is divided by the different properties of the materials. One should thus choose:

- Non-toxic materials.
- Renewable materials.
- Low energy content materials.
- Recycled materials (from recycling).
- Recyclable materials (to recycling).

### 3.3.1 Toxicity

Some materials and additives are best avoided since they are toxic or cause toxic emissions during their production, use or when incinerated or dumped.

The most hazardous chemicals are those which combine persistence (long-term survival in the environment) with biological availability and reactivity. The majority of such chemicals belong to three main groups of chemical compounds [Rydén et al., 2003].

*Polyaromatic hydrocarbons* (PAH) i.e. molecules composed of a number of aromatic rings.

*Metals*, especially heavy metals, and their organic compounds, especially mercury, cadmium and lead.

*Halogenated hydrocarbons*, organic substances with one or more hydrogen atoms replaced by chlorine (or bromine or fluorine, i.e. by halogens).

These materials are found not so often in the main material of a product (with some exception, e.g. lead batteries) but quite often in additives such as:

- Dyes (colorants).
- Heat or UV stabilizers.
- Fire retardants.
- Softening agents.
- Fillers.
- Expanding agents.
- Anti-oxidants.

Some dyes and fire-retardants are especially hazardous. In many countries the use of the most toxic materials is prohibited by law. It is evident that the use of material with the lowest toxicity should be chosen in the eco(re)design process.

The list of potentially toxic substances is virtually endless, and for many substances the toxic effect is unknown or not sufficiently documented. Toxic substances may be classified according to their mode of action [Walker et al., 2001] as:

*Genotoxic* – causing DNA damage. Genotoxic effects are detrimental for reproduction; they may damage the new individual as well as cause cancer through transformation of somatic cells.

*Neurotoxic* – affecting the nervous system.

*Immunotoxic* – interfering with the immune system.

*Metabolic disruptors* – e.g. uncouplers of oxidative phosphorylation or inhibitors of the electron transport chain.

*Osmotic disruptor* – disturbing osmoregulation.

*Hormone disruptors* – disturbing hormone regulation.

Providing evidence of a causal link between a chemical and an effect, such as tumour incidence, is a complex task and needs the consideration of both experimental results and epidemiological studies. The International Agency for Research on Cancer (IARC) is one scientific body performing such qualitative risk assessments on substances according to the evidence available on human or animal carcinogenicity. A number of other systems are used to estimate toxicity. The chemicals inspectorate of the country is normally responsible for providing information on the toxicity of various materials.

Heavy metals should be given special attention. The most dangerous are mercury and lead. Mercury is slowly becoming outlawed in several countries. Lead in leaded gasoline was particularly bad since it was part of the car emissions and inhaled on the streets. In Western Europe and North America unleaded gasoline is now used. Another concern is cadmium, which is now increasing in the environment. In many countries cadmium is outlawed in some products, e.g. dyes.

It is difficult to judge which is worse: a more dangerous but uncommon substance that causes a serious effect on a limited number of individuals or a very common substance that cause moderate effects on a large number of people. The Commission on Environmental Toxicology of the Committee of Ecology in the Polish Academy of Science prepared a list of the most deleterious substances to people. The list is based on analyses of such criteria as the emission level, toxicity, the area of target population, bioaccumulation, biomagnification, and effects on the physical and chemical environment. The higher the number given in the list, the greater the risk of health alterations from pollutants.

The result was the following: Sulphur dioxide (114), Suspended dust matter (108), Polycyclic aromatic hydrocarbons, PAH (88), Nitrogen oxides (83), Fluorides (72), Lead (52), Cadmium (42), Nitrate fertilisers (42), Carbon monoxide (29) and Pesticides (28).

## 3.3.2 Risk Management

Sometimes it may be necessary to include a hazardous substance in a product. It is then necessary to be aware of the rules applying to the management of such chemicals. All OECD countries, including the EU countries, have a system for listing toxic chemicals and a methodology for assessing the risk of chemicals. The assessment addresses both human toxicity and ecotoxicity, that is, toxicity to the environment and ecosystems.

The OECD protocol of 1989 includes the following steps: On the basis of collected data the *effects* on human health are identified and quantified. The *exposure* of humans resulting from release, transport and fate of a chemical in the environment is then assessed. The next step is *hazard assessment*, i.e. determination of the probable type and magnitude of toxic effects from the released compound. Finally *risk assessment*, which includes the estimation of the probability of the relevant effects occurring from the exposure to a chemical [Van Leeuwen and Hermens, 1995] is done.

The current EU Directives on Risk Assessment are based on Regulation EC 1488/94 (Box 3.3). In 2005 a new, comprehensive chemicals policy suggested by the Commission, the so-called REACH (Registration, Evaluation and Authorisation of Chemicals) was introduced. It will lead to a comprehensive scheme for management of all chemicals in the Union. Its im-

**Table 3.3 Toxicity of heavy metals to humans.** *The data are specified for different diseases caused by the heavy metals and the most sensitive age groups [Eco-indicator 99, 1999].*

| Metal | Type of disease/ function/organ | Sensitive age |
|---|---|---|
| Arsenic | Cardiovascular | Elderly |
| Aluminium | Nervous systems | Foetus, Children |
| | Osteoporosis | Elderly |
| Cadmium | Cardiovascular | Elderly |
| | Osteoporosis | Elderly |
| Chromium | Nervous systems | Foetus, Children |
| Cobalt | Osteoporosis | Elderly |
| Lead | Cardiovascular | Elderly |
| | Reproduction | Foetus, Young |
| | Nervous systems | Foetus, Children |
| | Osteoporosis | Elderly |
| Manganese | Nervous systems | Foetus, Children |
| Mercury | Reproduction | Foetus, Young |
| Nickel | Allergy and Hypersensitivity | Children |
| Selenium | Osteoporosis | Elderly |

## Box 3.3 Risk Management

All chemicals that are introduced to the market need today to be *registered and accepted* by the appropriate authorities, normally the Environmental Protection Agency or Chemicals Inspectorate of the country. The registration requires that basic data on the substance are provided. Data are used to assess the risk to human health and the environmental hazard of the compound.

Existing substances also need to be registered. In the EU existing substances are defined as those which were on the market prior to 1981 and which are listed in the EINECS database according to EC regulation 793/93 on evaluation and control of the environmental risks of existing substances. The EINECS database includes more than 100,000 substances. In the regulation the data gathering is the responsibility of the chemical producer or importer. For all products, sold or imported in quantities of 1 to 1,000 tonnes annually, the authorities will set priorities based on data on exposure in the environment and to people – as consumers and workers – and the long-term effects (the so-called IPS method).

Each substance has to undergo risk assessment. The risk assessment is carried out according to Risk Assessment Regulation EC 1488/94. The basic steps are hazard identification, exposure assessment, effects assessment, and risk characterisation.

Based on the results from the risk assessment a risk management strategy is developed. The basic steps are risk classification, risk-benefit analysis, risk reduction, and monitoring.

*Risk classification* is not only based on scientific considerations but also on what is considered to be an acceptable risk. Acceptability varies with time and place. What was acceptable in the past might not be so any longer, and risk acceptance varies between places and countries. One normally defines two risk levels, the upper risk level, maximum permissible risk, and the lower level, the negligible risk. The two limits create three zones: a black (high risk) zone, a grey (medium risk) zone, and a white (low risk) zone. An actual risk in the black zone is not accepted and legal action is taken, while no such action is needed in the white zone. Often one defines the low risk zone as 1% of the upper risk zone. Then there is a margin for possible underestimations due to e.g. additivity and synergistic effects between chemicals, and in general uncertainties and errors.

When the risk classification is done, there is the difficult task of *weighting the costs and benefits* of different measures of risk reduction. Before risk reduction one needs to know the technical possibilities, costs, the social and cultural factors, e.g. does it lead to unemployment, and the legislative possibilities? The cost-benefit analysis is carried out using estimates, most often in monetary terms, of the benefits for human health in terms of lives saved, lifetime extended, etc. Environmental risks are much more difficult to quantify, although costs for abatement or cleaning up can be used. From the estimates of cost one then decides on risk reduction measures.

*Risk reduction* deals with measures to protect people or the environment against identified risks. There are in general three approaches to risk reduction:

1. Classification and labelling of chemicals, to communicate the risk, according to an established system of symbols and regulations.
2. The ALARA (as low as reasonably achievable) approach which places the responsibility for lowering the risk on the operator, manufacturer or user.
3. Safety standards. These are fixed upper limits of exposure to certain chemicals as established in regulations. Examples of standards are threshold limit values, TLV, acceptable daily intake, ADI, and environmental quality standards.

Finally, risk management includes *monitoring and follow-up*. This is done to assure that the measures taken are completed and formulated standards relevant. Monitoring also serves the purpose of control, alarm, long-term trend study, and research to further identify the mechanisms of emissions, distribution, toxicity, etc.

*Source: Based on Van Leeuwen and Hermens, 1995.*

**Figure 3.4 Labels for chemical management.** *The labels are used to communicate the risks connected with the chemicals. The labels from top left indicate flammable, poisonous, corrosive, ecotoxic, allergic, explosive and oxidising. For each category there are strict rules for classification e.g. in terms of $LD^{50}$ on rats, or flame point, etc. The Chemicals Inspectorate in each country maintains databases where the regulations for storing, handling, and disposing of each chemical can be found.*

plementation is expected to last about ten years, that is, up to about 2015 (see Internet Resources).

If a chemical is classified as toxic or otherwise hazardous, e.g. if a biocide is included in a product, a proper management scheme has to go along with it. This includes information, especially proper labelling, and instructions for risk reduction (Box 3.3).

### 3.3.3 Renewable Materials

Materials should be avoided if they are from sources that are not replenished naturally, or take a long time to do so, implying that the source can be become exhausted in time. Examples are fossil fuels, tropical hardwoods, and metals such as copper, tin, zinc and platinum.

Some scientists regard depletion as a minor environmental problem since the materials involved eventually become very expensive, with the result that they will be recycled and alternative materials will be developed. However the rule is that more often the dissemination of a material from a deposit, to which it is not returned, leads to accumulation, and it becomes harmful in the environment long before the source is exhausted.

Non-renewable materials are used extensively. Oil is the basic raw material in petrochemical processes which dominates chemical industry. The replacement of oil-based chemistry is slowly introduced, under the name of "green chemistry". Basic chemicals are then made from biomass, e.g. ethanol from corn or wheat, and methanol from wood. These can be further processed to plastics and other materials. Vegetable oil produced from e.g. rape seeds are used in some processes. However 90-95% of oil products are incinerated in energy production and the replacement of fossil in the energy sector is thus the most urgent.

Non-ferrous metals are also used in large scale although they are non-renewable. Production of virgin metals is connected to considerable environmental impacts compared to use of recycled metal, or replacement options. For example the replacement of copper by optical fibres in communication systems has clear environmental benefits, as have the use of recycled metals, even if copper is not as such close to depletion or very toxic.

Recycling of metals is thus an environmentally important undertaking. When it comes to toxic metals such as lead, it is essential. Recycling can be made very efficient, more than 99% for e.g. lead, with carefully designed systems [Karlsson, 1997].

The issue of non-renewable materials is further discussed in Chapter 2.

## Hints for step 1
## Find Low Impact Material

**Non-toxic material**

1. Do not use materials or additives that are toxic. These include among others:
   - PCBs: polychlorinated biphenyls (prohibited in all countries).
   - PCTs: polychlorinated terphenyls.
   - Lead (in PVC, electronics, dyes and batteries).
   - Cadmium (in dyes and batteries).
   - Mercury (in thermometers, switches, fluorescent tubes).

   PCB and PCT are on the black list of substances banned in the 2002 Stockholm Convention. The others are on the grey list. They can be used with required precautions.
   Avoid the use of summer-smog-causing hydrocarbons.
2. Find alternatives for surface treatment techniques, such as hot-dip galvanization, electrolytic zinc plating and electrolytic chromium plating.
3. Find alternatives to non-ferrous metals such as copper, zinc, brass, chromium and nickel because of the harmful emissions that occur during their production.

**Energy efficient material**

1. Avoid energy-intensive materials such as aluminium in products with a short lifetime.
2. Find alternatives for exhaustible materials.
3. Avoid raw materials produced from intensive agriculture.

**Recycled and recyclable materials**

1. Use recycled materials wherever possible.
2. Use recycled plastics for the inner parts of products which have only a supportive function and do not require a high mechanical, hygienic or tolerance quality.
3. When hygiene is important (as in coffee cups and some packaging) a laminate can be applied, the centre of which is made from recycled plastic, covered with, or surrounded by, virgin plastic.
4. Make use of the unique features (such as variations in colour and texture) of recycled materials in the design process.
5. Preferably use recyclable materials for which a market already exists.
6. Avoid the use of polluting elements such as stickers which interfere with recycling.

### 3.3.4 Low Energy Content Materials

Some materials, whose extraction and production is very energy intensive, have higher energy content than others. Use of these materials is justified only if they lead to other, positive environmental features of practical use in the product. For instance, aluminium has high energy content. It is produced in a system which requires large amounts of electricity. Still it may be appropriate to use it in a product which is often transported and for which there is a recycling system in place. This is because aluminium is a light material and most suitable for recycling.

### 3.3.5 Recycled or Recyclable Materials

Recycled materials are materials that have been used in products before. If suitable, use these materials again and again so that the materials and the energy invested to make them are not lost. An example is copper. Recycled copper is about 50 times less material intensive than virgin metal, that is, the ecological rucksack of virgin copper is about 50 times larger than for recycled copper. Also recycled iron (6 times) and recycled aluminium is much less resource intensive than virgin metal [Schmidt-Bleek, 1994]. The use of recycled materials corresponds to "closing the materials flows" (Box 2.3 *Materials Management Strategies for Improved Material Flows*).

**Figure 3.5 Material substitution and dematerialisation**. *Exchanging copper wires for optical fibres is an excellent example of substituting a more (copper) to a less (glass) resource intensive material.*

## 3.4 Reducing Material Flows (Step 2)

### 3.4.1 Dematerialisation

The most direct way to reduce material flows is to dematerialise the product. There are several ways to achieve this.

*Make the product smaller*, and less material is used. Computers, now based on miniaturized electronic components, may provide the most dramatic example, when compared over the last 20 or so years.

*Increasing the rigidity* through construction techniques, such as reinforcement ribs rather than over-dimensioning the product, will lead to less material use, as will increasing its strength, e.g. by replacing a metal with a stronger alloy.

*Multi-functional use* of products also leads to dematerialisation. For example, a roof-mounted solar collector can also function as roofing.

Reducing the weight and size of a product is good not only directly for decreasing materials and resource use. There are also indirect effects.

Dematerialisation is very importantly related to the transport of the raw materials from supplier to producer as well as the final product to the retailer and or customer. Thus the space required for transport and storage is decreased by decreasing the product weight and total volume, as is the energy required for transport. This obviously improves the economy of production.

Another example: When using wood rather than cement for house elements, some 75 % of weight reduction was achieved. This decreased considerably the environmental effects of truck transport, as well as wear on roads [Karlsson, 1997].

Finally it may be said that quality is better expressed through good design rather than over-dimensioning the product.

**Hints for Step 2**
**Dematerialisation**

1. Aim for rigidity through construction such as reinforcement ribs rather than "over-dimensioning" the product.
2. Aim to express quality through good design rather than over-dimensioning the product.
3. Aim at reducing the amount of space required for transport and storage by decreasing the product's size and total volume.
4. Make the product collapsible and/or suitable for nesting.
5. Consider transporting the product in loose components that can be nested, leaving the final assembly up to a third party or even the end user.

### 3.4.2 Avoid Highly Resource-intensive Materials

Some materials are very resource intensive, and thus their use will lead to high material flows, and have a large environmental impact. There are many examples of such material, especially those with large energy intensity, large materials turnover, and where much transport is required.

By way of illustration, the United Kingdom currently uses approximately 10 tonnes of raw material to make one tonne of product. The nine tonnes that are not part of the product but still connected to the extraction of the useful material is called the *ecological rucksack* [Schmidt-Bleek, 1994]. They are merely a necessary part of extraction or are more or less unavoidable by-flows. Overburden has to be moved to obtain the useful materials and ores exposed to the applied extraction methods. Furthermore, high-value metals like copper are extracted from metal ores that contain only small amounts of metals. (The grade of copper ore can be as low as about 0.3%.) The non-metal remainder is discarded in the refining process and is part of the rucksack.

The relation between useful material and the rucksack varies considerably with different materials. For iron this factor is 1:6, but for copper it is normally 1:800. For those resources where the rucksack is large, the use of recycled material is an environmentally very favourable alternative [Schmidt-Bleek, 1994].

## 3.5 Design for Production (Step 3)

### 3.5.1 Decreasing Resource and Energy Flows

Good design also has to consider the production phase. Production techniques should have a low environmental impact: they should minimize the use of auxiliary (especially hazardous) materials and energy, lead to only limited losses of raw material and generate as little waste as possible.

Both extraction of raw materials and production of the product require energy. Substantial environmental gains can be achieved if energy use is minimised and the right kind of energy is used in both processes. Some extraction processes are energy intensive, e.g. for the production of aluminium.

There are also substantial business gains in reducing energy use. It reduces costs, especially if energy taxes are high. It reduces dependencies on energy, which makes production less sensitive to problems of energy deliveries, e.g. during cold winter days. Finally e.g. if fossil fuel is used for boilers etc, emission are reduced together with the volume of fuel.

The energy that is used should preferably come from renewable sources, such as biomass. Other renewable sources are wind power and hydropower. Today waste incineration is increasingly used. Finally solar energy, either as solar heating or as photovoltaic electricity, is rapidly becoming more important. If fossil fuel are used, natural gas is better than oil, and oil is better than coal, and it is better to choose low-sulphur grades fuels. To improve the energy situation in society taxation is used as economic incentives to make economic and environmental concerns coincide.

Cleaner production also (see below) aims to reduce energy consumption in existing production processes. It is important to motivate the production department of a company and suppliers to make their production more energy efficient. Encourage them to make use of renewable energy sources.

### 3.5.2 Cleaner Production Techniques

It is possible to review (audit) the production of a product to find opportunities for reduction of materials use, reducing the use of harmful materials, and reducing waste. This strategy is called *cleaner production* through process improvements. The environmental improvement of production processes is one of the components of the environmental management systems. The production department and suppliers work to improve the efficiency with which operational materials are used during production, for example, by good housekeeping, closed production systems and in-house recycling.

The cleaner production techniques include:

Using *fewer harmful auxiliary substances* or additives (for example, by replacing CFCs in the degreasing process and chlorinated bleaching agents); reducing the production con-


**Figure 3.6** *Electric powered cars, La Rochelle France. Photo: Barbara Kozlowska.*

### Hints for step 3
### Alternative Production Techniques

**Cleaner techniques**
1. Preferably choose clean production techniques that require fewer harmful auxiliary substances or additives. For example, replace CFCs and other chlorinated bleaching agents in the degreasing process.
2. Select production techniques which generate low emissions, such as bending instead of welding, and joining instead of soldering.
3. Choose processes which make the most efficient use of materials, such as powder coating instead of spray painting.

**Fewer production steps**
1. Aim to use the lowest possible number of production techniques.
2. Combine constituent functions in one component so that fewer production processes are required.
3. Preferably use materials that do not require additional surface treatment.

**Lower/cleaner energy consumption**
1. Aim to reduce energy consumption in existing production processes.
2. Motivate the production department and suppliers to make their production more energy efficient.
3. Encourage them to make use of renewable energy sources such as natural gas, low-sulphur coal, wind energy, water power and solar energy.

**Less production of waste**
1. Design the product to minimize material waste, especially in processes such as sawing, turning, milling, pressing and punching.
2. Reduce waste and the percentage of rejects during production and in the supply chain.
3. Recycle production residues within the company.

**Fewer/cleaner production consumables**
1. Reduce the production consumables required, for example, by designing the product so that during cutting, waste is restricted to specific areas and cleaning is reduced.
2. Improve the efficiency with which operational materials are used during production, for example, by good housekeeping, closed production systems and in-house recycling.

sumables required, for example, by designing the product so that during cutting, waste is restricted to specific areas and cleaning is reduced.

Using *techniques with low emissions*, such as bending instead of welding, joining instead of soldering.

Choosing processes which make the most *efficient use of materials*, such as powder coating instead of spray painting.

Preferably using materials that *do not require additional surface treatment*.

Cleaner production aims to reduce the number of production steps, by combining constituent functions in one component so that fewer production processes are required.

Cleaner production also aims to design the product to minimize material waste in processes such as sawing, turning, milling, pressing and punching. Here production residues should preferably be recycled within the process, or at least the factory.

Finally waste should be minimised, e.g. by reducing the percentage of rejects during production.

The strategy of cleaner production through process improvements is an approach with which industry is becoming more and more familiar. The environmental improvement of production processes is one of the components of the environmental management systems (EMS) which are now being used by industry, and which can be certified through the European Union Eco-management and Audit scheme EMAS, and the ISO 14001 standard.

## 3.6 Design for Distribution (Step 4)

### 3.6.1 Distribution Systems

The strategy of environmentally efficient distribution is there to ensure that the product is transported from the factory to the retailer and user in the most efficient manner. This relates to the product itself as well as the packaging, the mode of transport, and the logistics. If a project also includes a detailed analysis of packaging, the packaging should be regarded as a product in itself, with its own life cycle.

The most obvious possibility is to reduce transport as such by working with local suppliers in order to avoid long-distance transport.

The choice of transport mode is important. Ecodesign includes the avoidance of environmentally harmful forms of transport. Transport by air is the least environmentally favourable, road transport by truck, comes next, and transport by container ship or train is most preferable.

Efficient loading of the chosen mode of transport, as well as efficient distribution logistics, can also reduce environmental impact. Some rules are to introduce efficient forms of distribution, for example, the distribution of larger amounts of different goods simultaneously; and to use standardized transport packaging and bulk packaging (Euro-pallets and standard package module dimensions).

### 3.6.2 Estimating the Environmental Impact of Transport

Transport processes include the impact of emissions caused by the extraction and production of fuel and by the generation of energy from fuel during transport. The unit which you have to count (in the Eco-indicator method) is the transport of one tonne (1000 kg) of goods over 1 km (1 tonne x km). A different unit is used for bulk road transport. In the Eco-indicator three forms of transport are recognised:

- *Road transport*. In addition to transport for which the mass is the critical factor (tonne x km), an indicator has also been determined for those cases where the volume is the determining factor ($m^3$ x km).
- *Rail transport*. This is based on the average European ratio of diesel to electric traction and an average load level.
- *Air transport* for different types of cargo planes.

A loading efficiency for European average conditions is assumed. Account is also taken of a possible empty return journey. Capital goods, like the production of trucks and road or rail infrastructure, and the handling of cargo planes on airports, are included as they are not negligible.

**Hints for step 4**
**Distribution and Transport**

**Less/cleaner/reusable packaging**
This principle involves preventing waste and emissions. The less packaging required, the greater is the saving on materials used and the energy needed for transport.

1. If all or some of the packaging serves to give the product a certain appeal, use an attractive but lean design to achieve the same effect.
2. For transport and bulk packaging give consideration to reusable packaging in combination with a monetary deposit or return system.
3. Use appropriate materials for the kind of packaging, for example, avoid the use of PVC and aluminium in non-returnable packaging.
4. Use minimum volumes and weights of packaging.
5. Make sure the packaging is appropriate for the reduced volume, collapsibility and nesting of products.

**Energy-efficient transport mode**
The environmental impact of transport by air is far greater than transport by sea. This affects the choice of transport mode.

1. Avoid environmentally harmful forms of transport.
2. Transport by container ship or train is preferable to transport by lorry.
3. Transport by air should be prevented where possible.

**Energy-efficient logistics**
Efficient loading of the chosen mode of transport, as well as efficient distribution logistics, can also reduce environmental impact.

1. Work preferably with local suppliers in order to avoid long-distance transport.
2. Introduce efficient form of distribution, for example; the distribution of larger amounts of different goods simultaneously.
3. Use standardized transport packaging and bulk packaging (Euro-pallets and standard package module dimensions).

### 3.6.3 Packaging Systems

An important component of transport is the packaging of the product. Here considerable environmental gains can be made.

Some strategies can be considered even when designing the product itself. The space required for transport and storage can be minimised by decreasing the product's size and total volume. The product can also be collapsible and/or suitable for nesting, to reduce transport volume. It is also possible to consider transporting the product in loose components which can be nested, leaving the final assembly up to a third party or even the end user.

The principle of less/cleaner/reusable packaging intends to prevent waste and emissions. The less packaging required, the greater is the saving on materials used and the energy needed for transport. Some rules are:

If all or some of the packaging serves to give the product a certain appeal, use an *attractive but lean design* to achieve the same effect.

**Table 3.4**
*Example of environmental purchasing criteria for the retail trade.*

| Packaging |
|---|
| **Restriction on size** reduction of material usage |
| **Use mono-materials** improve initial use |
| **Limit variation in shape** less production pollution |
| **Reduce printing** less production pollution |
| **Reused materials** |
| **Chlorine-free bleached** |

Use *appropriate materials* for the kind of packaging, for example; avoid the use of PVC and aluminium in non-returnable packaging.

Use *minimum volumes* and weights of packaging.

For transport and bulk packaging give consideration to reusable packaging in combination with a monetary deposit or return system. Recycling processes cause an environmental load as all other processes do; however recycling processes also result in useful products. These products can be interpreted as an environmental gain, as they avoid production of materials elsewhere.

## 3.7 Design for "Green" Use (Step 5)

### 3.7.1 Reducing Energy Consumption During Use

The most important issues during use are energy and waste. First energy: design the product with use of the lowest energy consuming components available on the market. Avoid stand-by features. For example, about 70% of the energy consumption of a coffee machine during the lifetime in use is caused in the stand-by function. Only 30% of the energy consumption is directly connected with the purpose of the machine: making coffee. It is an extraordinary fact that only 10% of the total energy use during the lifetime is needed for heating the water! In the energy part during use there are a lot of environmental profits to harvest.

Using a *clean energy source* greatly reduces environmentally-harmful emissions, especially for energy-intensive products. Design the product so it uses the least harmful source of energy. Encourage the use of clean and renewable energy sources. An example is a solar heater which does not require energy for heating water during the summer.

Do not encourage the use of non-rechargeable batteries, for example; a walkman can be supplied with a battery charger, encouraging the use of rechargeable batteries. The best solution is to avoid batteries completely.

### 3.7.2 Reducing Waste Production During Use

A second step is to design the product so that the *fewer consumables* are required for its proper functioning. Some examples are:

Design the product to minimize the use of *auxiliary materials*, for example, use a permanent filter in coffee makers instead of paper filters, and use the correct shape of filter to ensure optimal use of coffee.

*Minimize leaks* from machines which use high volumes of consumables, for example, installing a leak detector.

Study the feasibility of *reusing consumables*, e.g. reusing water in the case of a dishwasher.

If an *auxiliary product* or consumable is to be improved in a project, it must be regarded as an individual product with its own life cycle. Ecodesign strategies must then be selected separately for each auxiliary product. Design the product to use the cleanest available consumables. Make sure that using the product does not result in hidden but harmful wastes, for example, by installing proper filters.

The product can also be designed to encourage consumers to *use products efficiently* and thus reduce waste. Mis-use of the product as a whole must be avoided by clear instructions and appropriate design.

## 3.8 Design for Long Life (Step 6)

### 3.8.1 Prolonging Product Life-time

The objective of the *initial life-time strategy* is to extend the *technical lifetime* – the time during which the product functions well – and the *aesthetic lifetime* – the time during which the user finds the product attractive – of a product, so that it will be used for as long as possible. All the principles that follow are aimed at this goal because the longer a product meets the user's needs, the less his/her inclination to purchase a new product.

It is, however, occasionally better not to prolong a product's lifetime; if the technical lifetime is much longer than the

**Hints for step 5**
**Design for "Green" Use**

**Reducing energy consumption during use**

1. Use the lowest energy consuming components available on the market.
2. Make use of a default power-down mode.
3. Ensure that clocks, stand-by functions and similar devices can be switched off by the user.
4. If energy is used to move the product, make the product as light as possible.
5. If energy is used for heating substances, make sure the relevant component is well insulated.

**Reducing waste production during use**

1. Design the product so that the user cannot waste auxiliary materials, for example, a filling inlet must be made large enough to avoid spillage.
2. Use calibration marks on the product so that the user knows exactly how much auxiliary material, such as a washing powder, to use.
3. Make the default state that which is the most desirable from an environmental point of view, for example, "no cup provided by drinks dispenser' or "double-sided copies".

aesthetic lifetime, a new balance must be sought. The technical lifetime must be made shorter or, preferably, the aesthetic lifetime must be longer. A shorter life is preferred if new, less energy-intensive alternatives are being developed.

Generally speaking we should design the product in modules so that the product can be upgraded by adding new modules or functions during its use when needed. For example, design a video recorder with a replaceable cover which can be removed, and eventually renewed. Further, make the most vulnerable components easy to dismantle for repair or replacement. Finally give the product an added value in terms of design and functionality so that the user will be reluctant to replace it.

### 3.8.2 Initial Lifetime Design Principles

Increasing the reliability and durability of a product is a familiar task to product developers. The most important rule to be applied is: develop a sound design and avoid weak links.

**Hints for step 6**
**Design for Long Life**

**Initial lifetime design principles**

1. Design the product in such a way that it needs little maintenance.
2. Indicate on the product how it should be opened for cleaning or repair, for example, where to apply leverage with a screwdriver to open snap connections.
3. Indicate on the product itself which parts must be cleaned or maintained in a specific way, for example, by colour-coded lubricating points.
4. Indicate on the product which parts or sub-assemblies are to be inspected often, due to rapid wear.
5. Make the location of wear on the product detectable so that repair or replacement can take place in time.
6. Locate the parts which wear relatively quickly close to one another and within easy reach so that replacements can be easily fitted.
7. Make the most vulnerable components easy to dismantle for repair or replacement.

**The product-user relationship**

1. Design the product so that it more than meets the (possibly hidden) requirements of the user for a long time.
2. Ensure that maintaining and repairing the product becomes a pleasure rather than a duty.
3. Give the product added value in terms of design and functionality so that the user will be reluctant to replace it.

Special methods, such as the failure mode and effect analysis, have been developed for this purpose.

Easy maintenance and repair are important to ensure that the product will be cleaned, maintained and repaired on time.

Choosing a modular structure or adaptable product makes it possible to "revitalize" a product which is no longer optimal from a technical or aesthetic point of view, thus enabling the product to still fulfil the (changed) needs of the user. Then the product can be upgraded by adding new modules or functions at a later date, for example, plugging in larger memory units in computers. Technically or aesthetically outdated modules can be renewed, for example, make furniture with replaceable covers which can be removed, cleaned and eventually renewed.

### 3.8.3 The Product – User Relationship

Classic design addresses the issue of the product-user relationship, to make an attractive product. But eco-designers, too, have to address this dimension of design. Now the aim is to reduce environmental impact by prolonging the use of a product.

One objective is to avoid trendy designs which may cause the user to replace the product as soon as the design pales or becomes unfashionable. Design the product's appearance so that it does not quickly become uninteresting, thus ensuring that the product's aesthetic life is not shorter than its technical life.

Most products need some maintenance and repair to remain attractive and functional. A user is only willing to spend time on such activities if he or she cares about the product. This principle of *Strong product-user relation* is aimed at intensifying the relationship between the user and the products.

Design the product so that it more than meets the (possibly hidden) requirements of the user for a long time. Ensure that maintaining and repairing the product becomes a pleasure rather than a duty. Give the product added value in terms of design and functionality so that the user will be reluctant to replace it.

## 3.9 End-of-life Design (Step 7)

### 3.9.1 End-of-life Design

A product's end-of-life system refers to what happens to the product after its initial lifetime. The end-of-life strategy is aimed to the reuse of valuable product components and ensuring proper waste management. Reusing the product, product components or materials can reduce the environmental impact of a product by reinvesting the materials and energy originally involved in its manufacture, and preventing additional hazardous emissions. If it is impossible to close the materials and

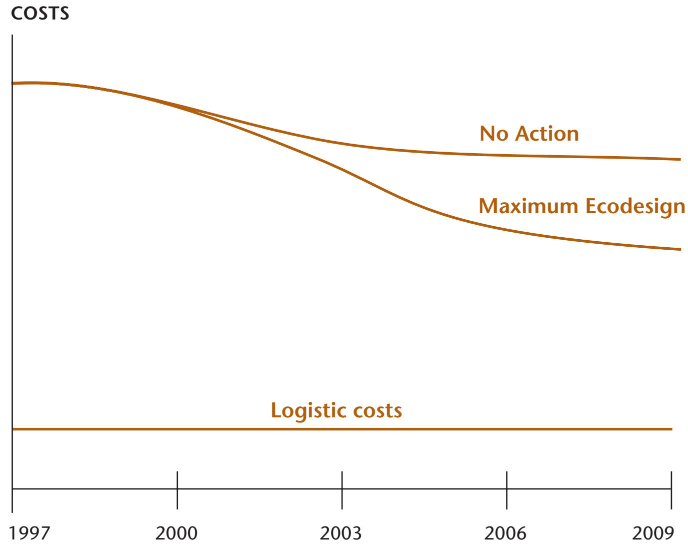



**Figure 3.7 Take back costs.** *The costs of take back of television sets change over time. Logistics costs are supposed to be constant [Eco-indicator 99, 1999].*

energy cycle in this way, safe incineration and waste disposal must be guaranteed.

The major issues for industry are the historical waste issue, the financing issue, and the material bans.

Firstly good design ensures that the construction does not become prematurely obsolete in a technical sense (to stimulate reuse of the product). It also ensures that the product can be dismantled in such a way as to ensure that the parts can be repaired, reused or disposed of separately.

Design for disassembly (from sub-assemblies to parts) means that the product should have a *hierarchical and modular design* structure; the modules can each be detached and remanufactured in the most suitable way. If non-destructive separation is not possible, ensure that the different *materials can be easily separated* out into groups of mutually compatible materials.

Secondly, cost is an important aspect of end-of-life management. An example of the emerging costs of take-back of televisions in Europe is given in the Figure 3.7. Televisions and computer monitors form 50-60% of the weight of the total waste stream of "browngood" products. It is expected that this figure will be even higher in the future due to the increasing portion of monitors. The graph shows clearly that a large reduction in the take-back costs of televisions can be achieved when the appropriate design, technological, economic and organisational conditions are fulfilled.

Thirdly, the presence of toxic material in a product will make disposal difficult, hazardous and costly. This is very of-

## Hints for step 7
## End-of-life Design

**Design for disassembly**

1. The product should have a hierarchical and modular design structure; the modules can each be detached and remanufactured in the most suitable way.
2. Use detachable joints such as snap, screw or bayonet joints instead of welded, glued or soldered connections.
3. Use standardised joints so that the product can be dismantled with a few universal tools – for example, use one type of screw.
4. Ensure easy accessibility of the product: use as few joints as possible and position joints so that the person responsible for dismantling the product does not need to turn it around or move it.
5. If non-destructive separation is not possible, ensure that the different materials can be easily separated out into groups of mutually compatible materials.

**Design for maintenance and repairability**

1. Design the product for dismantling to ensure easy accessibility of the product for inspection, cleaning, repair and replacement of vulnerable or innovation-sensitive sub-assemblies or parts, as detailed above.
2. Locate the parts that are relatively quickly worn out close to one another, so that they can be easily replaced.
3. Indicate on the product which parts must be cleaned or maintained in a specific way, for example; by using colour-coded lubricating points.

**Design for recycling**

1. Give priority to primary recycling over secondary and tertiary recycling.
2. Design the product for disassembly (from sub-assemblies to parts).
3. Try to use recyclable materials for which a market already exists.
4. If toxic materials have to be used in the product, they should be concentrated in adjacent areas so that they can easily be detached.
5. Integrate as many functions in one part as possible (a technique which can be used for this is Value Analysis).
6. Select one type of material for the whole product.
7. Use recyclable materials (such as thermoplastics, rather than laminates, filters, fire retardants and fibreglass reinforcements).
8. Avoid the use of polluting elements such as stickers which interfere with the recycling process.
9. Mark any parts made of synthetic materials with standardized material code.

ten the case with old materials that are scrapped after a long time, e.g. when removing a house. Here we may find PCB in walls and in joints; there may be mercury in electric equipment, such as switches, and lead in e.g. cables. Today similar difficulties are valid for some electronic equipment where flame retardants, often made from eco-toxic brominated organic compounds, are present.

Rules for how to handle hazardous wastes are becoming increasingly severe and costs are increasing. It is obvious that such materials should be avoided in any products.

### 3.9.2 Reuse of Products or Parts

The preferred option in disposal is to reuse the product as a whole, either for the same or a new application. The more the product retains its original form, the more environmental merit is achieved, providing that take-back and recycling systems are developed simultaneously.

This is best achieved if the product is given a classic design that makes it aesthetically pleasing and attractive to a second user. It is also important that the construction is sound so that it does not become prematurely obsolete in a technical sense.

The reuse option is also valid for parts of a product. This is well established for e.g. spare parts of cars, but regrettably many products end up in the incinerator or at land fill sites even though they still contain valuable components. A product may be reused if parts are replaced, and parts in a product may be reused even if the product as such has to be scrapped. It is useful to consider whether these components can be reused, either for the original purpose or for a new one. Remanufacturing and refurbishing, in the sense of restoring and repairing the sub-assemblies, is then usually necessary.

### 3.9.3 Recycling of Materials

Recycling, that is, reuse of the *material* in a product, is a common strategy because it requires relatively little time and only small investments: make the product so that it can be easily disassembled and use suitable materials in it. Another reason for the popularity of recycling is that it often brings financial benefits as well. The importance of recyclability is also easy to communicate both inside and outside a company.

Recycling requires that a system is set up for collecting the material, send it to the proper companies, and perhaps also a system for refunding. However, there used to be a tendency to claim that a product was recyclable even if no attempts were made to set up a take-back and recycling system. This tendency is now diminishing thanks to increased consumer and governmental awareness. For example, the US Federal Trade Commission prohibits the claim that a product is recyclable if the take-back infrastructure is not in place; and "thermal recycling" (incineration for recovering the energy value) is not regarded as recycling at all. If recycling is preferred to other strategies with more environmental merit, then the decision should be reconsidered.

There are several levels of recycling which together form a "recycling cascade": primary recycling (meant for original application); secondary recycling (meant for a lower-grade application; and tertiary recycling (such as decomposition of plastic molecules into elementary raw materials). These issues are discussed further in Chapter 10.

### 3.9.4 Incineration

If reuse and recycling are out of the question, the next best option is incineration with energy recovery (sometimes presented as "thermal recycling"), as is the case in modern waste incineration plants.

The more toxic materials there are in a product, the more the responsible party has to pay for its incineration. Toxic elements should therefore be concentrated and easily detachable so they can be removed, paid for and treated as a separate waste stream.

## Study Questions

1. What is the relation between Ecodesign strategies and Life Cycle Assessment (LCA)?
2. Which are the direct impacts on human health by using toxic materials?
3. Give some examples of alternatives for exhaustible (non-renewable) materials.
4. Give a short description of the dematerialisation process.
5. What kinds of techniques are available to reduce the impact on the environment during production?
6. Which factors influence the impact on the environment in the transport phase of a product life cycle?
7. What is exactly: Design for "green" use?
8. Describe the relation between "Design for long life" and the "Brundtland report".
9. Why is incineration the last alternative of the "End-of-life" step?
10. What is the purpose of the product review step?

## Abbreviations

| | |
|---|---|
| ADI | Acceptable Daily Intake. |
| ALARA | As Low As Reasonable Acceptable. |
| DNA | Desoxyribo Nucleic Acid. |
| EMAS | Environmental Management and Auditing System. |
| EMS | Environmental Management System. |
| IARC | International Agency for Research and Cancer. |
| ISO | International Organisation of Standardisation. |
| LCA | Life Cycle Assessment. |
| LD | Lethal Dose. |
| MET | Material, Energy and Toxicity. |
| OECD | Organisation for Economic Cooperation and Development. |
| PAH | Poly Aromatic Hydrocarbon. |
| PCB | Poly Chlorinated Biphenyls. |
| PVC | Poly Vinyl Chloride. |
| REACH | Registration, Evaluation and Authorisation of Chemicals. |
| RPD | Renewing Product Development. |
| SCM | Supply Chain Management. |
| UNEP | United Nations Environmental Program. |

## Internet Resources

International Agency for Research on Cancer (IARC)
http://www.iarc.fr

PRé Consultants – Ecodesign
http://www.pre.nl/ecodesign/default.htm

The Centre for Sustainable Design – ETMUEL Project: Ecodesign Tools
http://www.cfsd.org.uk/etmuel/tools.htm

Design for Environment (DfE) Guide of the Industrial Research Assistance Program – National Research Council of Canada
http://dfe-sce.nrc-cnrc.gc.ca/home_e.html

American Society of Preventive Oncology
http://www.aspo.org

Greywater Recycling & Irrigation Systems
http://www.greywater.com.au

Tennessee College of Architecture and Design – Ecodesign Resources
http://www.ecodesignresources.net

United Nations Environment Programme (UNEP) and Ecodesign
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

EcoDeNet ecoDesign Promotion Network
http://www.ecodenet.com/ed2001/

UNEP Sustainable consumption site
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

EnviroWindows. Environmental Information for Business and Local Authorities
http://www.ewindows.eu.org/ManagementConcepts/Ecodesign

Industrial Designers of America (IDSA) ecodesign section
http://www.idsa.org/whatsnew/sections/ecosection/

The Journal of Sustainable Product Design - Online
http://www.cfsd.org.uk/journal/index.html

EcoDesign Guidelines (DIA), Centre for Design, RMIT University, Melbourne, Australia
http://www.cfd.rmit.edu.au/programs/sustainable_products/ecodesign_guidelines_dia

REACH Directive of the EU
http://europa.eu.int/comm/environment/chemicals/reach.htm

# 4 Implementing Ecodesign

## 4.1 The First Steps

### 4.1.1 Steps to Introduce of Ecodesign

Ecodesign is still at an embryonic stage and until now has been undeveloped in several countries in the European Union, and even more so in the rest of Europe. The vast majority of industrial enterprises continue to manufacture products without taking environmental issues into account. Nevertheless, in recent years some environmental improvement has been noted in many products, mainly in the use of recycled materials, the incorporation of available technological advances at the production stage, and the reduction of the weight and volume of packaging used in distribution.

In many cases, these improvements are the outcome of a strategy for increasing financial rather than environmental benefits. They typically include *costs reduction* through energy or material saving and reduction of the cost for treatment of emissions. In other cases the cause has been the search for a *distinctive feature*, such as labelling (paints, lacquers, water-saving system). In yet other cases, the improvement has been in *response to legal regulations*, in particular directives on packaging, obsolete vehicles, electrical and electronic products, etc., or to circumstantial pressures.

Example of changes of the kind mentioned are the total or partial use of recycled material in urban furnishing sectors, industrial packaging of household goods, which is now a reality, and improvements in environmental management by SMEs (Small and Medium-size Enterprises) in response to demands from the major multinationals. The latter typically require environmental improvements, often certification, for the components that they acquire from their suppliers.

The introduction of ecodesign in enterprises is not a question of fashion or impulse, but rather a consequence of the fact that the companies and the society in which it operates gradually achieve a certain degree of environmental and financial maturity. It is no coincidence that German, Danish and Dutch enterprises are leaders in the application of ecodesign.

### 4.1.2 Tools to Help the Process

A growing number and variety of tools have been developed as a response to the challenges and pressures to do more business in environmentally friendly products. These tools include among others the following:

*Management systems.* These typically cover quality, environment, health and safety. They invest in people, as well as social and ethical issues. There are national and international standards for management systems, e.g. ISO 14001, EMAS, ISO 9000, AA 1000, SA 8000 and BS 8800.

**In this Chapter**

*Key performance indicators.* Indicators have often been developed in national environmental policy goals, e.g. as sustainable development indicators, they are found in the ISO 14031 EPI standards, and in the eco-efficiency indicators developed by the World Business Council for Sustainable Development;

*Product management.* Standards for product stewardship and consumer information have been developed in the ISO 14021 standards and in national and international Green Labelling schemes.

*Environmental reporting.* Environmental reporting is increasingly often included together with economic reporting from companies, municipalities and even on the national level. Standards typically include greenhouse gas emissions, waste, and water consumption. Examples include indicators and the Global Reporting Initiative, GRI.

### 4.1.3 Some Principal Approaches

When the management of a company or organisation wants to introduce environmental management and ecodesign as part of a policy change, some practical guidance is needed. The following concrete steps may be part of such a process:

*Introduce management systems.* Make a commitment to manage and improve your impacts – resources, energy and water, waste, transport, emissions, etc. – using appropriate management systems.

*Use environmental auditing.* Explore the scope for greater resource efficiency and benchmarking performance, e.g. by joining a governmental programme or a programme in an industrial association. Embrace the principles of producer responsibility by taking into account the different aspects from "cradle-to-cradle" in supplying products and services, working towards greater recycling and recyclability. Consider all the implications and opportunities at the design stage.

*Introduce corporate responsibility.* Tend to social responsibilities through: 1. good employer practices by, for example, encouraging fairness at work and helping staff to develop their skills; 2. being a good neighbour, responsive to the local community; 3. being an ethical trader.

*Communicate with stakeholders.* Report on environmental performance towards meaningful targets, using relevant certification schemes and making product declarations that are legal, decent, honest and truthful.

*Cooperate in the supply chain and the sector.* Work with others either through the supply chain, specifying what you want and helping others to comply, or as part of concerted sectoral action to help improve overall performance, safeguarding yours as well as theirs.

## 4.2 Management

### 4.2.1 The Importance of Knowledge Management

Ecodesign is a knowledge-intensive activity. Everything revolves around knowledge, not only knowledge of ecodesign itself, but also knowledge about how to acquire information, knowledge of the learning process of people, the expertise of teachers, and, not the least, knowledge of how to organise, operate and maintain an educational and applied research organisation.

In a knowledge-based society, the acquisition of knowledge and the practice of using knowledge will be the deciding competitive factors. Knowledge about the company's products, services and internal processing is combined with knowledge about the customer. The goal is to make ecodesign deliver new services, as well as complete solutions to customers.

Knowledge should be put to systematic use in order to determine what knowledge an organisation needs to achieve its aim. Nonaka and Takeuchi [1995] take this a step further by claiming that for a KIO (Knowledge Intensive Organisation) the creation of knowledge is the key to a lasting competitive advantage. Nonaka and Takeuchi express this as "in an economy where the only certainty is uncertainty, the sure source of lasting competitive advantage is knowledge."

Thus in order to preserve the competitive advantage companies must continue to learn and innovate continually, and often radically. Few companies, however, have much time to allocate to this process. If the innovation process focuses on minimising the operational costs, mostly by optimal utilisation of new technological possibilities, time is created for education and innovation.

It is obvious that training will be an important component for companies in a knowledge-based society, and experts will play an important role here both in the public and private sector. This training should concern a core-competence of ecodesign, but also about the competence-development process itself. This investing in knowledge makes several traditional economic concepts difficult to apply. A company or organisation cannot "own" a person in the same way as a machine, and thus investing in a person is very different from investing in equipment, buildings etc. Rules for protecting intellectual property exist (patent rules) but do not suffice here. The company has every reason to create a working place that makes their personnel want to stay and contribute.

### 4.2.2 Managerial Changes

Small companies are facing increasing pressure from environmental inspection and control, and contractors to improve their environmental performance. However, pressures associated with limited time, resources and competence often push the environment far down on their agenda. Few small companies have investigated the inherent business benefits of operating an effective Environmental Management System, EMS, in this case ecodesign. They are not aware that EMS and ecodesign could help them avoid inefficiency and enhance legal compliance.

Inertia within such small firms is extremely difficult to overcome. The obstacles and barriers associated with implementation, include:

- Perceived lack of time.
- Lack of policy and documents.
- Lack of understanding of EMS (ecodesign) requirements.
- Lack of sufficient regulatory and legal knowledge.
- Economic constraints.
- Difficulty in defining economic benefits.

In order to improve or to change the management system, a functional approach is needed. The functional approach in turn asks for an integration of management, much in the same way that "quality" pressures have provided for an integrated approach of marketing and selling of products and services. Here management of design, development, production, selling and after-sales activities is integrated, and these activities cannot be divorced from each other. Their importance and interdependence far outweigh the justification for ignoring and reducing the importance of any function.

In today's almost global economy, where there are increasing pressures of competition within many industries and commercial sectors, the application of the *five functions of management* (Figure 4.1) [James, 1996] has never been more necessary or decisive. Their effective application to quality management is imperative. The activities involved in each function are in summary:

*Planning.* This is the determination of targets and goals that need to be achieved, and using plans, procedures and strategies to achieve them.

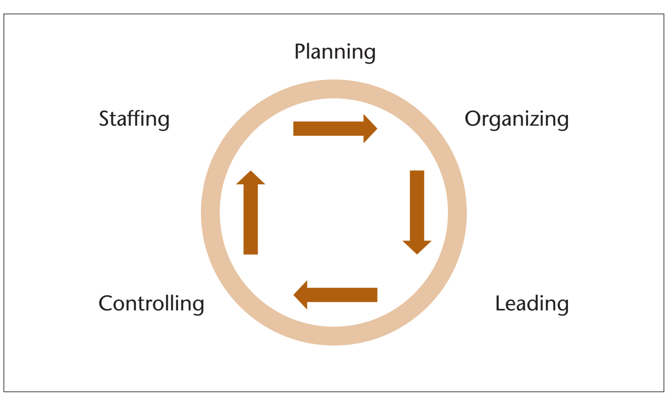


**Figure 4.1** *Management function cycle [James, 1996].*

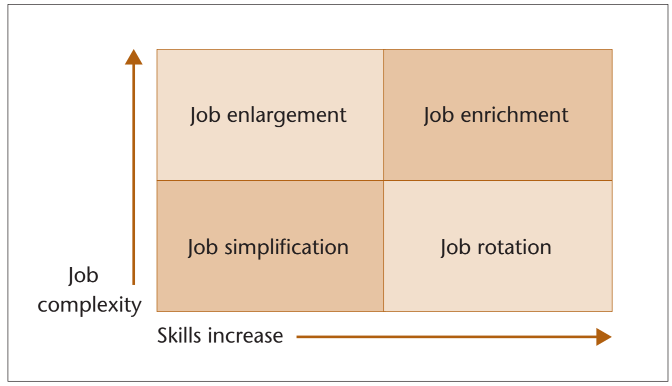


**Figure 4.2** *Job design method [James, 1996].*

*Organising.* Determining the right task to perform and ensuring it is distributed efficiently and effectively. It can be applied to individuals, groups, departments or whole organisations.

*Leading.* Giving direction to others and getting others to do the task given. It means motivating subordinates and maintaining morale.

*Controlling.* Determining appropriate standards, applying them and ensuring that they are achieved and taking corrective action when necessary.

*Staffing.* Deciding the type of people to be employed and training them to do the jobs allocated.

### 4.2.3 Job Design

The process from product development to product innovation contains a series of activities derived from many sides of the company, from company and marketing strategy to the whole product collection. In the development and innovation processes everybody is involved, from designer to engineer, but also the general management, marketing and sales, the quality and maintenance officer, production staff and so on. Implementing ecodesign will thus lead to an increased complexity of the work conducted, and therefore to new specialisations and new skills. It has a major influence on job design.

Job design (Figure 4.2) [James, 1996] is an important aspect of a quality-oriented organisation. It is not sufficient to give people extended job specifications – they must be trained and educated, and they must be motivated sufficiently to carry out that job.

Job design provides the greatest influence on organisational structure. The larger the organisation, the greater the likelihood that specialisation will be needed. This occurs because there is a limit to the amount of work – physical or mental – that an individual can perform. Consequently, as an organisation grows, so does the need and pressures for specialisation. Fredrick Taylor (1856-1915) used specialisation as the basis for his methods of working. Different work requires different skills, attitudes and aptitudes. Specialisation therefore allows individuals to develop more focused skills and competencies in order to carry out their tasks and job responsibilities more effectively.

The four areas in Job design, concerning the complexity and personal skills, are;

*Job simplification.* The process of narrowing the specialising of a job, so that the job-holder has fewer activities to perform.

*Job enlargement.* The development of job specifications that increases the variety of activities that an individual carries out. It is more challenging and there is room for increased mental stimulation through increased innovation and risk-taking. It also provides improvements in operator skills and competencies through increased skills development, training and education.

*Job rotatio*n. The rotation of individuals through different job sets and a planned order. Job rotation increases skills and releases workers from the effects of boredom related to job simplification and job enlargement.

*Job enrichment.* The process of developing job content that increases job skills, the potential for individual growth through education and training, achievement, recognition and responsibility.

**Table 4.1** *Barriers and opportunities to implementation of ecodesign and manufacture of ecodesign [Rieradevall, 2002].*

| Group | Barriers | Opportunities |
|---|---|---|
| **Designers and technicians** | Considering the product in isolation, and applying the concept of recycling.<br>Lack of awareness of ecodesign.<br>No use of tools for environmental improvement and processes.<br>Intuitive approach to environmental improvement.<br>Environmental improvement of products only in the use of recycled materials. | Innovation.<br>Concept of life cycle.<br>Integration of environmental aspects in financial and social projects.<br>Product system. |
| **Enterprises** | Priority for treatment and recycling.<br>Lack of awareness of ecodesign.<br>Few environmental inventories.<br>Lack of awareness of overall impact of their products' life cycles.<br>Make environmental improvements to products only to obtain cost savings. | Identification of stages with greatest impact.<br>Financial efficiency thanks to cost reductions in production, transportation, use and end-management of waste.<br>Differentiation from competitors.<br>Advance on regulation: IPP, ecodesign regulations, directives on end-management of products.<br>Improvement of image, marketing and communication.<br>Greater safety and reduction of insurance costs.<br>Movement towards sustainable enterprises. |
| **Consumers** | Environmental responsibility for product beyond consumers' control.<br>Preferential choice of ecoproducts not widespread.<br>Lack of awareness of eco-labels.<br>Little importance seen in environmental considerations in the home.<br>Very little awareness of the environmental implications of products. | Green purchasing.<br>Financial savings from reduced consumption of energy and materials during use.<br>Improvement of end-management of products.<br>Enhanced quality of life.<br>More environmentally friendly lifestyles. |
| **Governments** | Green purchasing by governments only beginning and of minor importance.<br>Few resources dedicated to research and development on new ecoproducts.<br>Little promotion of eco-labels.<br>Priority for end-process strategies (treatment and recycling). | Contribution to definition of new environmental policies.<br>Image of environmentally friendly institution.<br>Resources savings.<br>Reduction of overall environmental impact.<br>Greater participation by all players.<br>Commencement of programmes for sustainable development. |

## 4.3 Challenges, Difficulties and Opportunities

### 4.3.1 Challenges

The Badalona Declaration, adopted by the International Forum City, Company and Environment held in the city of Badalona, Catalonia, Spain, in the framework of the Sesame Network Cities, (see Internet Resources) says:

*One of the future objectives for companies must be to adapt industry and other production activities in order to progress towards sustainability. Progress must be made towards environmental improvement and protection in order to ensure further and better growth: the environment is an opportunity for innovation rather than an obstacle to business development.*

And later regarding consumers:

*The environmental crisis is giving rise to the appearance of a new profile of consumer, who shows greater awareness of the ecology and greater solidarity, plays a proactive role in providing solutions, and acts as a responsible consumer.*

We may translate the conclusions from the Badalona Declaration into challenges for ecodesigners. In summary they are:

Ecodesign means that the effect a product has on the environment should be considered and reduced at all stages along the product life cycle. These stages include the development of a product, its manufacturing, its marketing and distribution, its use and finally, its disposal.

Ecodesign products should be "flexible, reliable, durable, adaptable, modular and dematerialised". In addition to being environmentally adapted, the products should be economically and socially justifiable.

Ecodesign has emerged from a series of improvements in environmental protection. This development started with end-of-pipe solutions, continued with prevention to avoid waste and toxic substances in production (cleaner production), and led to efforts to minimise the environmental impact of a product, applied to the entire life cycle, from raw material extraction to the ultimate disposal of a product (cleaner products). Today the aim is to optimise the entire socio-economic system of the product as well as that of its use to meet the criteria of sustainable development for the future.

Ecodesign aims at advancing prosperity while reducing "environment spending".

### Box 4.1 Case study: Implementing Ecodesign in Small and Medium-sized Companies

In a study by Delft University in the Netherlands (C.G. van Hemel, 1997) 73 small and medium-sized companies were interviewed about an ecodesign project which had been initiated by the university. Best represented were companies working with metal products, machinery, wood and furniture, electronics, and rubber and synthetics.

Three quarters of the companies had no earlier experience of ecodesign. They nevertheless saw ecodesign as an opportunity rather than a threat, and as an investment that would be paid back. The main reasons to start ecodesign included a wish to increase the quality of a product, anticipating future developments, and product innovation. But reasons also included personal responsibility towards the environment, and supply chain pressure.

A total of 602 individual ecodesign improvements were suggested (mostly based on the ecodesign strategy wheel). 30% of the improvement options were completed after 10-16 months, and after 3 years a total of 247 (41%) were completed. The dominating strategies were selecting low impact material, lower product weight, and recycling. Lower on the list were cleaner production, more efficient packaging, low energy consumption in the use phase, and the use of recycled materials in the product.

Ecodesign had been applied to 39 products. They were as follows:

- 1 new product
- 21 products which were thoroughly redesigned
- 13 products which were slightly improved
- 4 packagings of products were improved

The experiences of the companies were overwhelmingly positive. Most companies said that they were now able to apply ecodesign themselves, and 90% said that they would recommend ecodesign to others. 71% said that they would continue with ecodesign, and 30% had already started ecodesign projects with other products, and even more had initiated research on products. 25% were going to integrate environmental concerns in their quality requirements, and another 25% included product related issues in their EMS.

A majority of the companies expected the ecodesign to promote their business. 67% expected their products to increase market shares, and 56% expected to enter new markets. 25% expected a profit to be made within two years.

It was clear that internal stimuli to make ecodesign were more important than external stimuli. It was also clear that in many cases ecodesign worked together with business interests, cost reduction, image improvements, and new market opportunities. However, external stimuli were also relevant, especially if larger investments were needed.

### 4.3.2 Difficulties

When proposing that a company should apply ecodesign, one is regularly met by a series of questions and objections. The two most common – with short answers – are:

*Why should business care about its impact on society?* Because the introduction of practices and technologies that favour the reduction of waste and pollutant emissions and the saving of energy will be increasingly necessary in order to improve the profitability and competitiveness of companies.

*Shouldn't a business only take action if there is a business case?* That is true, but another reason is that one needs to meet regulations. Environmental criteria are today incorporated in all phases of a product, from conception, design, manufacture, distribution, use and wasting. The whole life cycle should therefore be redesigned from the new viewpoint of the Integrated Product Policy (IPP) of the European Commission. Ecodesign falls within this new vision of products and makes them feasible.

Other questions related to business difficulties are:

*Should business care:*

- if young people don't have the skills that business needs?
- if the climate is changing and it is getting hotter or colder?
- if customers care about the business impact on the environment?
- if customers cannot pay their bills?
- if customers have extra needs?
- if regulators, government and stakeholders demand action?
- if business affects public health and safety?
- if business is missing the opportunity to improve its reputation or gain a competitive edge?

We can't ask these questions and then conclude that business shouldn't care. Every business has an impact on the society in which it operates. Actively managing that impact is just common sense. It is not an original, nor indeed an entirely creative thought, but it is true. The best programmes in this area to date embrace good management disciplines, passionate personal commitment from people across the business, and a readiness to account openly for their impact.

Table 4.1 shows the barriers encountered by the main players in connection with implementing ecodesign, and production, purchasing and end management of ecoproducts.

### 4.3.3 Opportunities

In spite of the barriers and difficulties, the implementation of ecodesign and the manufacture of ecoproducts offer advantages for all players involved. Table 4.1 is a summary of these advantages and opportunities.

## 4.4 Examples of Implementation of Ecodesign

### 4.4.1 17 Examples of Ecodesign

#### Example 1: Using Recycled Resources. Recycled non-chlorine bleached coated paper. France

The French paper producing company Matussière & Forest has taken the technology of environmentally adapted paper one step further. Already in the 1980s non-chlorine bleached paper became common (after consumer pressure) and in the 1990s the techniques for producing good quality paper from recycled paper developed dramatically. With the new product it is now possible to coat paper produced from 100% recycled paper. For this new product development the Matussière & Forest was awarded the European Business Award for the Environment 2004. The paper is of equally high quality as ordinary paper and does not require more energy in its production. Paper production is typically in the early stages of a supply chain, and the new paper has the potential to improve many products.

*www.matussiere-forest.fr*
*www.eu-environment-awards.org/html/winners_2004.htm*

#### Example 2: New Concept Development. Shared use of cars. The Netherlands

Selling the use instead of the ownership of products is a speciality of the Dutch company Greenwheels. Greenwheels is one of the companies that have developed an innovative system to enable people to share the use of cars. When cars are shared by multiple users, there are environmental benefits. First, the cars are maintained and repaired regularly by the operator, which increases their reliability, performance and energy efficiency. Secondly, the cars are used more intensively and need to be replaced more often than traditionally-owned cars. Energy-efficient innovations can therefore be launched on the market earlier than when cars are owned individually. Thirdly, customers sharing a car tend to use it more sparingly, and cover short distances using public transport or bicycles. In the Netherlands, half the numbers of trips by car are made over distances of less than five kilometres!

The idea looks like ordinary car rental but has features that make it more appealing. The cars are placed in parking lots or garages near customers, to make access easy. Parking places are reserved by Greenwheels, which is important, especially in crowded cities. The cars may be used also for short periods of time, such as one hour, which keeps costs down. Reservations are made by phone 24 hours a day. The customers pay a yearly subscription fee in addition to the fee per kilometre and hour.

*www.greenwheels.nl*

A number of other companies have taken up the idea of car pooling. Carplus in the UK can be found on *www.carplus.org.uk*. See also *www.carplus.org.uk/carclubs/case-studies.htm*. Similar clubs are available in Germany (Cambio Car), Italy (ICS), Switzerland (Mobility), Finland and Sweden (City Car Club, *www.citycarclub.se*). The Stockholm club has 13 Ford Flexifuel models, which run on ethanol or petrol. The Uppsala association (*www.bilpoolarna.se*) has at present (March 2005) 51 members, of which 48 are households and 3 are organisations.

### Example 3: Integration of Functions. A solar collector balcony. Germany

The German company Viessmann has developed the Solar-TubuSol, a vacuum tubular collector which can be used in place of large solar panels. One application is the so-called solar balcony balustrade. This heat-providing balcony balustrade is constructed from tubes of thick borosilicate glass. A durable vacuum-sealed glass/metal collector ensures safety and a long service life. Thanks to this innovation, no separate attachments for the balcony balustrade and the solar collectors are required. This saves materials and energy. Furthermore, the vacuum tubular collector out-performs flat-bed collectors by about 30 percent, given diffuse sunlight. This works partly because the individual tubes can be directed optimally toward the sun. The system also encourages the use of solar energy of solar panels in architectural design. The design was selected for the Top Ten in the 1996 Industry Forum Design Competition.


**Figure 4.3 A solar collector balcony** *(Example 3). This balustrade is used both as a solar panel and as a balcony balustrade. The Vitosol 200 model is found in the City of tomorrow (Bo01 exhibit in 2001) in Malmö. Photo: Viessmann Werke GmbH & Co KG.*

300 m$^2$ of the solar Collector Balcony was used in Malmö´s City of Tomorrow large architectural and urban planning exhibit in 2001, and received the Saxonian environmental award that year.

*www.viessmann.com*

### Example 4: New Concept Development. The SMART car. Switzerland

A combined development by Mercedes-Benz and Swatch MH, the Smart is an example of re-orientation of the function a product actually fulfils. The Smart was introduced in 1998 as a super-compact, city-compatible vehicle by a new company MC Micro Compact Car AG, located in Biel, Switzerland. The two-seater has a reduced fuel consumption (some 4 litres/100 km) and is only 2.50 metres long. With different drive modes – petrol and diesel – and with both sedan and convertible models available, the Smart can be tailored to meet the wishes of most purchasers. Emissions are low.

The car also offers various options for linking with other means of transportation: "Only by combining public transport concepts with car sharing and pooling plans can future demands for mobility be fulfilled" (Smart press release). Tests are going on in the field of pool leasing and car sharing. Access to a large car pool with various models and rental arrangements will be possible for Smart drivers. A substantial market potential is expected in the multiple-car utilisation field.

*www.smart.com*

### Example 5: Energy Optimization. The green light traffic signal. Denmark

Technical Traffic Solution (TTS) in Denmark developed a new, innovative traffic light using light-emitting diodes. This offers

**Figure 4.4 The Smart car** *(Example 4). This car for city traffic is small (2.5 m) easy to park and uses little fuel (about 4 litres/100 km). It contributes to a reduced resource flow.*

many advantages over traditional traffic lights, including energy conservation, the use of environmentally-sound material (aluminium), less or almost no operation and maintenance costs, increased safety, and elegant design.

Rapid developments in semiconductor technology have made it possible to produce a light-emitting diode (LED) with the internationally required standard specifications. Light-emitting diodes have many advantages compared to traditional bulbs. The production processes and materials used are environmentally good. The LED uses considerably less energy than traditional bulbs. They have a lifetime which is typically over 10 years, while traditional bulbs with short lifetime of (typically 11 months with a burning time factor of 60%) need to be changed about once a year. In addition, the new lenses of the traffic lights do not need to be regularly cleaned which, combined with the LED, make the new lights practically maintenance free. TTS received the Danish Design Award and in 2002 the Danish EU environmental award for their product Green light based on the LED technique.

*www.tts.dk*

*www.eu-environment-awards.org/html/winners_2002.htm*

### Example 6: Resource Saving.
### The green furniture project. Denmark

The Green Furniture Project is a Danish initiative to design and produce furniture with a careful choice of materials and techniques. The project originated in a research project at Aarhus School of Architecture in Denmark and was further developed by the organization 'Det Grønne Møbel'. By 1996, a collection of 11 products had been developed through the cooperative efforts of industrial designers, experienced carpenters and other craftsmen from small workshops in the area. The furniture, produced with the cleanest production techniques possible, is now being made and sold from local workshops. At least 80 percent of the raw materials used in production must be renewable local materials such as wood, ecologically-grown flax and waste wool. Seaweed collected at the nearby coast substitutes for freon-inflated foams, and the use of other low impact materials such as traditional bone-based glue is combined with new products such as natural paints. The furniture basically consists of wood from elms that have died as a result of Dutch elm disease.

*www.dgm.dk*

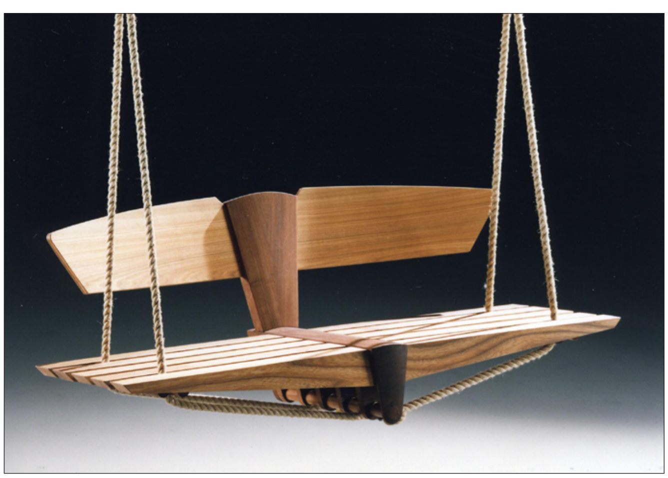


**Figure 4.5 The green furniture project** *(Example 6). The furniture in this project are built from local clean resources, and wood from trees killed by Dutch elm disease.*

### Example 7: Using Recycled Resources.
### Patagonia fleece-jacket. USA

Recycled plastics can be used for many purposes. In 1993 the Patagonia Company developed a polyester fleece made of recycled soda bottles to make sports clothing. The first product was a fleece jacket. This PCR® (Post-consumer recycled) fleece has diverted over 86 million bottles from landfills to date. The PCR® filament yarn contains 30-50% post-consumer feed stock – soda bottles, polyester uniforms, tents and garment – and 50-70% (the rest) post-industrial feed stock, mostly from yarn and polymer factory waste. This material offers the same performance characteristics as virgin yarn at a competitive price with less environmental harm.

The Patagonia Company has profiled itself as an environmentally concerned company. In 1984, they began pledging at least 1% of sales (or 10% of pre-tax profits, whichever is greater) to the protection and restoration of the natural environment. In 1993 Patagonia began to incorporate environmental ethics into the product line. In 1995 the company switched


**Figure 4.6 The Patagonia fleece-jacket** *(Example 7). This jacket is made from plastics from consumer waste, such as soda bottles, and industrial waste from polymer factories.*

to 100% organically grown cotton in all sportswear. In 2004 the company gave away 2.1 million dollars for the environment. To date they have donated over 20 million dollars. They continue their work on reducing the environmental harm in all of their products and processes.

*www.patagonia.com*

### Example 8: Energy and Resource Efficiency. SCOOLER, an electric scooter. France

The Scooler is an electric scooter developed by the French company ALEL. It was launched in 1996 and then received the first prize in the 1996 Ecoproduct Competition organized by the French Chamber of Commerce and the Ministry of Environment. The Scooter offers a driving distance of 95 km (at 45 km/h) before the batteries have to be recharged. The scooter is built to have a long life (80 000 km instead of 20 000 km for a conventional scooter) during which the batteries do not need to be replaced. The company guarantees the take-back and recycling of the nickel-cadmium batteries. Since transmission uses a leather belt instead of a gear box, no transmission oil is required. Energy costs for the Scooter are 25 Euro cents for 100 km instead of 4.5 Euro for a conventional scooter with a combustion motor.

*www.alel.biz*

**Figure 4.7 Electric scooter** *(Example 8). This scooter (the Scooler) runs on battery for 95 km on 45 km/h. Costs is about 10% of running a traditional gasoline motor scooter.*

### Example 9: Dematerialisation. SoftAir air furniture. Sweden

The manufacture of a SoftAir inflatable sofa, and other SoftAir furniture, requires only about 15% of the materials, energy and resources needed to make a traditional sofa. Costs of transportation and storage of inflatable furniture are of course also very low. Life cycle assessment shows a decrease of about 85% of the total amount of energy that is consumed when making a traditional sofa. The material used in SoftAir products is polyolefin, which is 100% recyclable. The basic material pure air is of course also eco-friendly. The designer Jan Dranger won the IF Ecology Design award 1999 for the SoftAir concept.

*www.softair-furniture.com*

### Example 10: Reduced Toxicity and Improved Energy Efficiency. CFC-free refrigerator. Germany and Turkey

Refrigerators and freezers have been manufactured and designed without ozone-depleting substances (freons, Chloro Fluoro Carbon, CFC) for some ten years. The German-Turkish company Arçelik began manufacturing CFC-free refrigerators (using R-600a and R-134a refrigerants) in 1994, although the Turkish market is allowed to use CFC until 2010 according to the Montreal Protocol. c-Pentane/iso-Pentane are used as blowing agents inside the polyurethane insulation.

In addition the refrigerators are very energy-efficient. In 2004 Arçelik received the Energy+ award from the European Commission for the outstanding performance of its Blomberg CT 1300A model refrigerator. This 288 l refrigerator uses 0.375 kWh per 24h (equivalent to 16 W). Its energy efficiency index of 19.8 is the lowest so far in Europe.

*www.arcelik.com.tr*
*www.energy-plus.org:1001/english/awards/*

**Figure 4.8 Inflatable furniture** *(Example 9). The SoftAir inflatable sofa only requires some 15% of the resources needed for a conventional sofa. It consists mostly of air. Of course the sofa may also have a textile cover.*

### Example 11: Improved Energy Efficiency.
### Wind-up radio, flashlight etc. UK

The FREEPLAY radio is an example of a product which is much more environment-friendly when used than its competitors, thanks to its remarkable energy source. The Englishman Trevor Baylis wanted to develop a radio to enable communication by radio in countries where an electric power supply through direct current or batteries was little available. He developed the wind-up radio FREEPLAY, which uses no power but functions through a winding mechanism consisting of a carbon steel spring, which drives a generator. The spring can be wound up in only 20 seconds, and gives 40 minutes of radio play. The radio is also available with a DC input jack as a supplement to the winding mechanism. The original BayGen wind-up radio has now been improved with a built-in flashlight. The rechargeable battery pack can store excess power with its built in solar panel as well as ordinary AC.

The wind-up technology has also been developed by several other companies including large enterprises like Grundig and Philips as well as small but more specialized companies like Freeplay Energy plc in the UK. Freeplay Energy in partnership with Motorola also makes a small wind-up combined flashlight & generator which can charge mobile phones. After winding less than a minute the user can generate 5 minutes of talking time.

*www.freeplayenergy.com*

### Example 12: Multiple Improvements.
### Green consumer electronics. The Netherlands

Philips has developed a framework to measure environmental performance of its consumer electronics products using structured benchmarking process addressing weight, hazardous substances, energy efficiency, packaging, recycling and disposal. The procedures were developed at Philips Consumer Electronics Environmental Competence Centre in cooperation with the Technical University of Delft in the Netherlands. The products had the requirement that they should be 10% more energy efficient than other comparable products on the market.

The result of this work is the marketing of a product line called Green Flagships including about 100 different products from LCD-monitors and TV-sets to small digital audio players. At present (2005) about eight new Green Flagships products are produced each year.

*www.misc.ce.philips.com/greenflagship/*

### Example 13: Long Life.
### Tripp-trapp chair. Denmark

The Tripp-Trapp chair from the Danish manufacturer Stokke has been on the market for nearly 20 years and is a classic example of a product which combines multi functionality with elegant simplicity. The chair can be modified and adjusted to fit the growing child. Since it is built of wood it lasts for years and years and its lifetime continues in the second-hand market.

*www.stokke.com*


**Figure 4.9 Wind-up radio** *(Example 11). The Freeplay Radio offers the latest in self-sufficient technology: a choice of wind-up, solar and rechargeable batteries. Also available for flashlights mobile phones etc.*

**Figure 4.10 Tripp-trapp children's chair** *(Example 13). This is a classic in good design. It can be adjusted to the growing size of a child, is robust and mostly wooden.*

### Example 14: Recycling and Good Waste Management. The think chair. Germany

The Think Chair was developed by the company Steelcase Inc. in close collaboration between researchers, manufacturers and designers. The design-company McDonough Braungart Design Chemistry, famous for its ”cradle-to-cradle” product concept (C2C), worked with the manufacturer Steelcase, while the Institute for Product Development in Denmark did a life cycle assessment. The chair is ergonomically perfected but it also has ecological benefits. The material of the chair is all environmentally safe and consists to 41% of recycled lightweight materials. When wasted it is very easy to disassemble and 99% is recyclable.

The Environmental Product Declaration (EPD) of Think Chair, created according to ISO 14025 LCA, accounts for resource depletion, waste, global warming potential, as well as smog. The chair has won a number of internationally well-recognised design awards and the work to improve it still continues. Steelcase Inc. has incorporated the C2C-concept in the development of other products. The “Think” of the chair, as Steelcase put it, stands not only for the intelligent brain but also for concern for the environment.

*www.steelcase.com*
*www.mbdc.com*

### Example 15: New Concept Development. Technology equipped clothing. USA

Perhaps many would associate Technology Enabled Clothing as something from the science fiction world but TEC is a company that has developed a system to conceal conduits inside garments which can be connected to USB-compatible devices such as hands-free headsets for cell phones and MP3-players. They call it Personal Area Network (PAN). No more loose wires. From an environmental point of view one notice that the garments have built-in solar cells. The cell phone or mp3-player charges as you take a walk in the sun.

*www.technologyenabledclothing.com*

### Example 16: Increased Energy Efficiency. Dye-sensitized solar cells. Netherlands

The dye-sensitized solar cell replicates the most important principles of its prototype, photosynthesis. Due to its simple construction it offers the hope of a significant reduction in the cost of solar electricity. “Their manufacture is relatively simple on laboratory scale.” In fact, according to ECN-researcher Jan Kroon, “you can practically make this solar cell in your kitchen with $TiO_2$ (commonly used in toothpaste) and raspberry juice”. “The present state of this technology has resulted in working prototypes of cells and small modules, but these are not available on the market yet. We expect that within five

**Figure 4.11 The Think Chair** *(Example 14). This chair was developed using an LC impact assessment of all materials. It is made from 41% recycled material and is 99% recyclable. Photo: Steelcase Inc.*


**Figure 4.12 Technology Enabled Clothing** *(Example 15). The jacket provides a “Personal Area Network”, in which you may recharge batteries by photovoltaics, connect mobile phones or use a MP3-player. Photo: Scottevest Inc.*

years these solar cells will appear on the market for low-power applications either on glass or flexible substrates (i.e. calculators, watches, price labels). Hopefully, this will function as a stepping stone for the introduction of high power applications, which are mainly intended for outdoor use." Their efficiency is only 5-10% on small areas, which is much less than conventional silicon solar cells, but the promise of low manufacturing costs and versatility, make practical applications of these photovoltaic devices feasible in the future.

*www.ecn.nl*

### Example 17: Dematerialisation.
### The Mac minicomputer and MP3-player. USA

Apple computers have from the outset been quite compact and thus dematerialised. Apple Ipod, a combined hard disk and MP3-player, with disk space of 60 GB, has the size 10x6x2 cm. The Mac mini computer H4 with frequency of 1.42 GHz and 80 GB hard disk and 1 GB RAM memory, equipped with CD player and DVD burner has the dimensions 5x16.5x16.5 cm. Although the computers have to be equipped with key-boards and monitors, the Mac mini computer constitutes a considerable dematerialisation.

*www.apple.com*

## 4.4.2 Comments on the Survey of 17 Cases

Table 4.2 gives an overview of 17 cases of ecodesign, which are described in more detail further on. The cases are collected from all over the world, with some slight over-representation of German, Dutch and Danish cases. The table features all kinds of products and services, from small household products, such as boilers, chairs and TV sets, to larger products, e.g. cars, and finally services, although the service amounts to the use of a product. They are reviewed according to which stage in the product life cycle environmental benefits are most important, separated as production, use and wasting phases.


**Figure 4.13 Mini MP3-player and computer** *(Example 17). The Apple iPod and Mac mini computer illustrate a dramatic case of dematerialisation. Despite their compact design, they are equipped with large hard disks and many other functions*

12 products out of the 17 feature improvements in the production phase. Most typically the production uses renewable or recycled material. In several cases care has been taken to avoid toxic material. Many of these products are very much dematerialised, in some cases by a factor of close to 10.

Many products, 11 out of 17, offer environmental gains during their use phase. Most typically, products are very or extremely energy efficient due to ecodesign. Secondly, products are more repairable, since parts can be exchanged easily, and therefore have an extended lifetime. Some products have been designed not to have any toxic material, and others, such as the scooter and the SMART car, are zero-emission vehicles and thus are in the same category of non-toxic products.

Finally 9 out of the 17 descriptions specifically mention environmental benefits during the wasting phase. Recycling of the materials, easy end-of-life disassembly of the product are included, as well as the absence of toxic material, or – for the batteries for the scooter – the producer will take back and recycle the product.

In several cases it is specifically mentioned how environmental benefits, resulting from ecodesign, also have economic benefits, both for the producer and the customer, user, when less energy and material is used. In other cases there are social benefits (less toxic).

## 4.4.3 Companies which have Implemented Ecodesign

Many large multinational manufacturing companies have established ecodesign for many years. These include Apple computers and Philips electronics. IKEA has for several years an environmental strategy including education of all personnel, review of all providers and ecodesign of all products, based on the Natural Step principles. Similar strategies are used by e.g. Skanska and hotel chains such as Scandic hotels (member of the Hilton family).

But there are also several smaller companies, mostly those in which ecodesign is part of their business concept. The AXIS water boiling kettle, the FREEPLAY wind-up radio, and the Viessmann solar balcony are interesting examples. They prove that it is not always necessary to have the resources of a large company to achieve success. A good idea may stand on its own feet.

Some of the companies explicitly refer to the need for an extensive development effort to reach the product they wish to produce. Examples include the Bryant & May matches (without toxic phsophorous) for the environment and of course the larger companies such as Apple and Hitachi. In some cases, again, a good idea may be enough. Greenwheels shared use of cars is in this category.

Table 4.2 *Review of 17 examples of ecodesign.*

| No | Product | Production phase | Use phase | Wasting phase |
|---|---|---|---|---|
| 1 | *Matussière & Forest.* Recycled non-chlorine bleached coated paper. | Using recycled paper as resource. | | Recyclable. |
| 2 | *Greenwheels.* Shared use of cars. | | Increased efficiency: Cars maintained better and used more often. | Cars replaced sooner after more mileage. |
| 3 | *Viessmann.* Solar collector balcony. | Multi-functionality: saves materials and energy. | Increased energy efficiency: heat-providing balcony balustrade. | |
| 4 | *SMART.* Super-compact car. | Dematerialisation. | Low weight, reduced fuel consumption, zero emissions. | |
| 5 | *Technical Traffic Solution (TTS).* Traffic light using light-emitting diodes. | Dematerialisation. | Increased energy efficiency; much decreased maintenance costs. | Dramatically increased life span. |
| 6 | *Det Grønne Møbel.* Furniture with a careful choice of materials and techniques. | Renewable local materials; very clean production techniques. | | Material recyclable or burnt as biomass. |
| 7 | *Patagonia.* Polyester fleece jacket made of recycled soda bottles. | Using recycled plastics as resource. | | Material recyclable. |
| 8 | *ALEL.* Electric scooter. | | Energy efficient; no fossil fuels, not even transmission oil; cheaper to drive. | Long life; Company takes back and recycles the nickel-cadmium batteries. |
| 9 | *SoftAir.* Inflatable furniture. | Dematerialisation: Requires only 15 % of resources of conventional furniture. | | All material (polyolefin) is recyclable. |
| 10 | *Arçelik.* CFC-free refrigerators. | No use of ozone-destroying CFC. | Energy efficient. | |
| 11 | *FREEPLAY.* Wind-up radio, as well as flashlight and mobile phone. | | Functions through a winding mechanism to charge radio, mobile or flashlight; no energy | |
| 12 | *Philips Consumer Electronics Environmental Competence Center.* Green Electronics. | | Products use 10% or less energy than conventional consumer electronics. | |
| 13 | *Stokke.* Tripp-Trapp chair. | Using wood as material. | Can be adapted to the age of the growing child. | Long life; attractive on the second hand market; recyclable wood. |
| 14 | *Steelcase.* The Think Chair. | Resource is environmentally safe and 41% recycled material. | Ergonomically perfected chair. | Easy to disassembly; 99% recyclable material; The C2C concept. |
| 15 | *Technology Enabled Clothing.* Technology equipped clothing. | | Multifunctional; Equipped with solar cells to recharge equipment. | |
| 16 | *Energy research Centre of the Netherlands (ECN).* Dye-sensitized solar cells. | Simple material such as $TiO_2$; easily manufactured: still in development stage. | | |
| 17 | *Apple.* Mac minicomputer and MP3 player. | Dematerialisation. | | |

## Study Questions

1. What kinds of profits are gained by implementing Ecodesign other than Environmental ones?
2. Make a short list of ideas, subjects and/or findings for the design of an Ecodesign implementation plan.
3. Select one of the many examples and discuss its pros and cons
4. Visit one of the links and select one more interesting example.

## Abbreviations

| | |
|---|---|
| C2C | Cradle-to-Cradle. |
| EPD | Environmental Product Declaration. |
| EPI | Environmental Performance Indicator |
| EPM | Environmental friendly Product Development. |
| HVLP | High Volume Low Pressure. |
| IPP | Integrated Product Policy. |
| KIO | Knowledge Intensive Organisation. |
| KM | Knowledge Management. |
| PAN | Personal Area Network. |
| PBIT | Profit Before Interest and Taxation. |
| RPD | Renewing Product Development. |
| SME | Small and Medium-sized Enterprise. |
| TEC | Technology Enabled Clothing. |

## Internet Resources

BADALONA International Business Centre
www.bcin.org

Beispiele für ökointelligente Produkte und Dienstleistungen Ökodesign - Eine Initiative für nachhaltige ökointelligente Produkte, Wien, Österreich
http://www.ecodesign-beispiele.at/

PRé Consultants: life cycle tools to improve environmental performance & sustainability
http://www.pre.nl/ecodesign/default.htm

UNEP Sustainable consumption site
http://www.uneptie.org/pc/sustain/design/design-subpage.htm

EnviroWindows. Environmental Information for Business and Local Authorities
http://www.ewindows.eu.org/ManagementConcepts/Ecodesign

Eco Smart Design, a product-oriented design program by ESS (Environmental Systems & Solutions), Craigavon Northern Ireland and Product Ecology Pty Ltd, Melbourne Australia
http://www.ecosmartdesign.co.uk/abouttheprogramme/index.asp

Industrial Designers of America (IDSA) ecodesign section
http://www.idsa.org/whatsnew/sections/ecosection/

Eco-Gallery SDN BHD, Johor, Malaysia
http://www.eco-gallery.com/

Ecco design company
http://www.eccodesign.net/eco_design.htm

Design school HTL-Hallein, Hallein/Salzburg, Österreich
http://www.htbl-hallein.salzburg.at/eco.design/ecoziel.htm

EcoDesign Guidelines (DIA), Centre for Design, RMIT University, Melbourne, Australia
http://www.cfd.rmit.edu.au/programs/sustainable_products/ecodesign_guidelines_dia

BioThinking, Edwin Datschefski, London
http://www.biothinking.com/pd.htm

# 5 Introduction to Life Cycle Assessment

## 5.1 Principles of LCA

### 5.1.1 How to Assess Environmental Impact

Environmental awareness of our industrialised societies has been developing rapidly for the last several decades. A shift in attitude towards the environment has brought a new term – *environmentally friendly*. Although a commonly-used description, it is not easy in fact to determine which products or, in broader context, which forms of human activity, are environmentally friendly. Another crucial issue is to find out what can be done to improve the environmental profile of a certain product or process. How can we assess possible benefits gained by changing the mode of production, usage or disposal of a product. In other words: how do we determine which one of several alternatives is more, or the most, environmentally friendly. Answers to such questions are important for a sustainable development.

It has been proved that when evaluating the environmental friendliness of a product, intuition is not enough. In a survey on green milk packaging a majority would certainly find a returnable milk bottle much preferable to a disposable milk carton. The reason is that the bottle is recyclable and the cardboard cartons are not. The bottle is therefore expected to lead to significantly lesser amounts of waste in comparison to cardboard cartons. These two environmental problems – recycling and waste production – are broadly reported in the mass media. In reality the overall difference between the alternatives is insignificant. The two kinds of packaging contribute to completely different environmental impacts. Admittedly, glass can be reused and recycled, but it is connected with high costs of transportation and cleaning. This is not the case for disposable cartons. In conclusion, the most advisable solution would combine the environmental advantages of the two considered alternatives, namely being recyclable but at the same time light (for instance a square polycarbonate bottle) [Heijungs et al., 1996]. The environment is a complicated network of many unexpected and unexplained interrelationships. Sometimes a solution which appears to be excellent might only shift the problem to another life stage of the product, or to another sort of impact.

*Life cycle assessment (LCA)*, is a rather new tool in environmental management, which has the capacity – at least in principle – to answer these seemingly easy questions: Is a product environmentally friendly? Which product is greener? What is then life cycle assessment and how can it be used. These are the questions we will address in this chapter.

**In this Chapter**

1. Principles of LCA.
   - How to Assess Environmental Impact.
   - Definitions of LCA.
   - The Goals and Applications of LCA.
   - Developments of LCA.
2. The Qualitative (approximate) LCA.
   - The Red Flag Method.
   - The MET Matrix.
3. Quantitative LCA Methods.
   - The Components of Quantitative Methods.
   - Goal Definition and Scope.
   - The Functional Unit.
   - System Boundaries and the Process Tree.
4. Inventory Analysis and Allocation.
   - Inventory Table.
   - Allocation.

### 5.1.2 Definitions of LCA

According to the ISO DIS standards, LCA is defined as a method for analysing and determining the environmental impact along the product chain of (technical) systems. It includes the various types of technical conversions that occur in the manufacturing process. These consist of the *change of material chemistry* (chemical conversion), material formulation, or material structure; *the removal of material* resulting in an increase of (primary) outputs over the inputs; and the *joining and assembly of materials* resulting in a decrease of (primary) outputs over the inputs. This general description has been specified in two widely known definitions of LCA.

According to ISO 14040, the formal definition of LCA is as follows:

"LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:

- Compiling an inventory of relevant inputs and outputs of a product system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study."

The definition by SETAC (Society of Environmental Toxicology and Chemistry), which was a pioneer in publishing its "Code of Practice", states that:

"Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal."

Since the late sixties and early seventies much attention has been given to life cycle technology. Over the years life cycle assessment has developed (Box 5.1). It means that the analysis called LCA gathers a number of more or less different methods. What they have in common is the holistic viewpoint on the life cycle and dealing with environmental aspects of all emissions and material consumption resulting from the life cycle. Nevertheless, there is still no internationally accepted methodology of LCA. The international standard now developing is based on the ISO 14040 series.

With respect to the way of conducting an LCA we can separate qualitative and quantitative methods [Jensen et al., 1997].

**LCA in Brief**

LCA is a technique for evaluating the *environmental effects* of a product or a service over the entire period of its *life cycle* ("from cradle-to-grave").

*Qualitative methods* draw conclusions straight from the life cycle. The *quantitative methods* evaluate the environmental impacts by mathematical processing of the data describing the life cycle. They may even result in the calculation of a single score representing the environmental friendliness of a product.

### 5.1.3 The Goals and Applications of LCA

LCA assess the environmental effects of a product or service or, more commonly, the effects of a change in the production or design of a product or service.

The *goals and applications of LCA* range over a scale from short to long term. It includes:

- Short-term process engineering.
- Design and optimization in a life cycle (type 1).
- Product comparisons including product design and product improvement.
- Eco-labelling in the medium and long term (type 2).
- Long-term strategic planning (type 3).

Each goal requires its own type of analysis and modelling. Data requirements can then be specified more precisely, both for case applications and for generic databases.

Thus when performing an LCA, all the emissions and the resource consumption which enter or leave a life cycle are translated into the environmental problems that they potentially may contribute to. The two terms environmental effects and life cycle both need to be properly understood.

*Environmental effects* are the consequences of a physical interaction between a system studied and the environment. In practical use all environmental effects are represented by several categories of environmental problems. The most commonly used are:

- Resource depletion
- Global warming
- Ozone depletion
- Human toxicity
- Ecotoxicity
- Photochemical oxidation
- Acidification
- Eutrophication
- Land use
- Others (including solid waste, heavy metals, carcinogens, radiation, species extinction, noise).

The other term, crucial to understanding the holistic approach of the life cycle assessment, is the *life cycle* itself. It encompasses all the processes required to fulfil the function provided by a product or service (Figure 5.1), [Stachowicz, 2001; Walz, 2000].

At present LCA is used for the following fields of application:

- Infrastructure
- Process industry
- Energy production
- Transportation
- Heavy industry
- Consumer goods
- Livelihood

## Box 5.1 The History of Life Cycle Assessment

**Several tools for assessing environmental impacts**
The roots of Life Cycle Assessment reach back to the 1970s. At the time methods such as integral environmental analysis, ecobalances, resource and environmental profile analysis etc were used. Over the years the experiences of working with these tools fed into the Life Cycle Assessment method around 1990. At a conference organised in 1991 by the Society of Environmental Toxicology and Chemistry (SETAC) it was agreed that the proper name for LCA should be Life Cycle Assessment (rather than Analysis). In 1997 the International Organisation for Standardization published its first standard for LCA , ISO 14040.

LCA is one of several tools for assessing the environmental impact of a product or service. Others include Environmental Impact Assessment (EIA), Ecological Risk Assessment (ERA), Material Flows Analysis (MFA) as well as several more economic tools such as Cost Benefit Analysis (CBA). LCA is (normally) by far the most comprehensive (all inclusive) of these.

**1970s and 1980s – studies on beverage packaging**
The first study considered to be an LCA was made in 1969-70 for Coca-Cola by Midwest Research Institute in the US. This was one of several studies on packaging and waste. The question was which is better to manufacture and use: beverage (steel or aluminium) cans, plastic bottles, refillable glass bottles or disposable containers. Coca-Cola asked for an all inclusive study of the energy, material and environmental costs of the entire chain from resource extraction to manufacture, use and finally waste of the containers. The researchers conducted a so-called Resource and Environmental Profile Analysis (REPA) for all the alternatives.

The first European study was done by Ian Boustedt at the Open University in the UK in 1972. Inspired by the Coca-Cola study and its development he constructed a case on milk bottles to be used in a text book. The work fitted well with the at times rather heated public debate on the pros and cons of returnable and non-returnable bottles for milk, beer etc. Later in the 1970s a German study was done on meat trays, and in Sweden on PVC bottles for Tetrapak, a very large company producing containers for beverages. The result came out in 1973, at the time when plastic bottles could be incinerated in the first waste incineration plants (in Malmö) and the impact of HCl, produced in the incineration, could be estimated.

**The 1990s - LCA methodology develops**
In the coming several years hundreds of similar studies were published, especial in the USA, UK, Germany and Sweden. Most often the databases used were made public, which was very important for the possibility of conducting more studies. In the mid 1980s first Switzerland, completed in 1990, and later Denmark and Sweden published very large packaging studies, in early 1990 and 1991. These early studies were mainly concerned with the energy and material used and waste released during the life cycle. It was not until later that the impact assessment was included in a more serious manner.

The first scientific conference on LCA was organised by the Society of Environmental Toxicology and Chemistry (SETAC) in 1991. Methodology was a main topic to discuss. Especially the reporting of environmental impacts was rather simple. Working groups were organised to develop recommendations for industry. LCA of products was now considered a more important tool for environmental improvement than just minimising the emissions from production. The main impact may be elsewhere, not least in the waste phase.

**Into the 2000s**
**– Standardisations and Code of Practices**
Efforts were made to make LCA data publicly available and to develop software for calculations. There were also strong forces requiring a standardisation of the methodology to make different studies comparable, especially to make it less easy to use LCA for promoting specific products. The first Code of Practice for LCA was published by SETAC in 1993. This work on methodology, especially concerning impact assessment, is still ongoing. The ISO standards for LCA have been published since 1997 (ISO 14040) and later 1998, 2000 and 2002. In 2005 the European Commission introduced its European Platform on Life Cycle Assessment as a component in the IPP Directive. Its initial phase, 2005 to 2008, intends to reduce costs for LCA studies, to harmonise quality control, and to produce consistent data basis. The intention is to establish LCA as a reliable support in decision making and promote its acceptance in governments.

*Source: Baumann and Tillman, 2004.*

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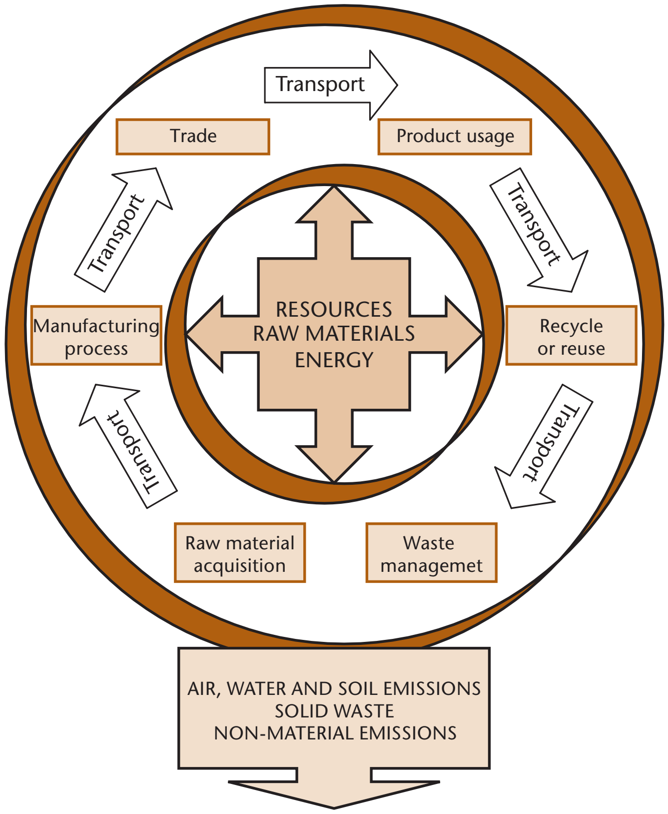



**Figure 5.1** *Product life cycle [Stachowicz, 2001; Walz, 2000].*

### 5.1.4 Developments of LCA

There are many shortcomings in the applications of LCA techniques. Up to the present time, the main focus of research in LCA has been on developing LCA as a tool rather than a system [Hauschild and Wenzel, 1998]. Hence, there has been an emphasis upon assessment of potential environmental effects. Relatively little attention has been paid to, for example, the process of defining alternatives for consideration in an LCA, or choice of weighting factors. Further research could allow us to develop LCA as a system capable of assessing the environmental impact per function, system needed or money spent. Such a new approach would allow us to *search for conditions for reaching maximum cost-effectiveness* with respect to the environment for a function or product. Then the ratio of system cost/environmental impact could be maximized. A method to do this will be discussed later, primarily developed and tested to support Life Cycle Management (LCM) of capital assets [Stavenuiter, 2002].

Today's LCA approaches are valid *only for incremental changes in the product* of interest and *defined geopolitical regions*. To use LCA to provide answers to long-term planning issues is more difficult. Radical changes in technologies, legislative constraints or policy goals need to be anticipated. Future developments of key technologies and entire economic sectors will thus affect the outcome of the LCA. They have to be defined carefully [Frischknecht, 1997].

Current LCA integrates over time and space. A desegration of these two parameters are needed to get a more precise result. First *environmental impact is depending on location*. For example acidification is very different in different places. Desegregation of the inventory of impact as to location is a matter of practicability. It has been done in several studies, to allow for a differentiated impact assessment.

*Desegregation in time* is needed to allow for a differentiated impact assessment. One reason for "flattening out time" in current practice is that LCA is supposed to support decision making and affect future decisions, while for an actual system a substantial part of the processes have already taken place. For example, the factory which is bringing out a new car next year will itself have been set up some 10 years ago. The decisions in car design will not influence past decisions but only exert influences on production facilities yet to be built.

## 5.2 The Qualitative (approximate) LCA

### 5.2.1 The Red Flag Method

Qualitative LCA methods do not use systematic computational procedures to assess the environmental profile of the system under study. They analyse the life cycle of a product in environmental terms directly on the basis of emissions released and the consumption of raw materials. Assessing the seriousness of the impacts directly from the impact table requires thorough training and extensive knowledge. A decisive role is played by relevant experiences of the expert carrying out the evaluation.

The *red flag method* (RFM) may serve as an example of a qualitative method. There are a number of companies working with RFM, for instance Philips. The first step is, as usual, preparing an impact table. This gathers all emissions and material consumption during the whole life cycle of a product. Then, the items which are harmful to the environment are red-flagged. Red flags can occur along with emissions of CFCs (chlorofluorocarbons), toxic substances, greenhouse gases, etc. or where scarce materials are consumed. The red-flagged process or product should then be given special attention and if possible excluded from the life cycle of the product. Even though this approach is fairly easy, there is a major obstacle. The red flags many times are placed in nearly each process or life stage without, any distinction between small and large quantities of unwanted emissions. In practice not all these stages can be removed or changed. In these cases the red flag method does not provide a sufficiently qualified evaluation and is not useful.

A piece of the impact table for production of 1kg of EPDM rubber with flags is shown in Table 5.1.

### 5.2.2 The MET Matrix

Another qualitative method for assessing life cycle of a product is the so-called *MET matrix* (materials, energy and toxicity).

A MET analysis consists of five stages. The first is a discussion of the social relevance of the product's functions. Then the life cycle of the product under study is determined and all the relevant data is gathered. Next the data is used in which is the core of the MET matrix method: completing the matrix (Table 3.1). The processes in the life cycle are then entered in the matrix divided into three categories: material consumption, energy consumption, and emissions of toxic substances. As in the case of Red Flag Method, completion of the MET matrix can be done only with an aid of environmental experts. Finally, when the most significant environmental problems are identified, possible steps to improvement of the product or service should be outlined.

The qualitative methods in general have poor reproducibility. The reason is that they require support provided by experienced environmental experts, and that experts often come to different conclusions. The scientific support for making reproducible and reliable judgements is so far lacking.

**Table 5.1** *Impact for production of 1kg of EPDM rubber.*

| No | Substance | Compartment | Unit | Amount |
|---|---|---|---|---|
| 1 | Baryte | Raw materials | g | 7.07 |
| 2 | Nickel | Raw materials | mg | 23.9 |
| 3 | Sand | Raw materials | g | 4.39 |
| 4 | Acetone | Air emissions | µg | 954 |
| 5 | Cd | Air emissions | µg | 978 |
| 6 | He | Air emissions | mg | 110 |
| 7 | Methane | Air emissions | g | 9.94 |
| 8 | As | Water emissions | mg | 1.24 |
| 9 | K | Water emissions | mg | 555 |
| 10 | Na | Water emissions | g | 26.5 |
| 11 | Cr | Soil emissions | µg | 460 |
| 12 | Oil biodegradable | Soil emissions | µg | 72.6 |

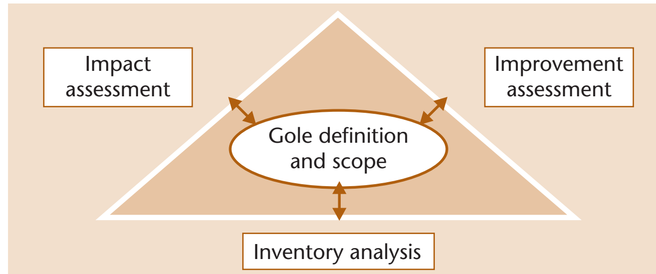



**Figure 5.2** *Interrelation of LCA phases [Hillary, 1995].*

## 5.3 Quantitative LCA Methods

### 5.3.1 The Components of Quantitative Methods

There are a number of different quantitative LCA techniques. These are in practice applied as a group of methods which use classification, characterisation, normalisation and weighting. The most important are:

- Eco-points
- Eco-indicator
- EPS system
- MIPS concept

The methodological framework of all the LCA techniques is based on ISO standards 14040-43.

A complete LCA consistent with ISO standards consists of four interrelated phases (compare with the definition of LCA given by ISO):

1. *Goal definition and scope.*
2. *Inventory analysis.*
3. *Impact assessment* with four sub-phases: classification, characterisation, normalisation, weighting.
4. *Improvement assessment.*

Interrelations among the LCA phases make LCA an iterative process (Figure 5.2), [Hillary, 1995]. The calculation and evaluation procedure is repeated until the analysis reaches the required level of detail and reliability.

The first step in an LCA is a raw assessment to determine critical points in the life cycle and find directions for further studies. Such a quick analysis is called *screening*. Sometimes it is enough to answer all the questions asked in the goal definition.

*Goal definition and scope* is crucial for all the other phases. These include gathering data, that is building a model of the life cycle, choosing appropriate environmental effects to consider (local, global?), and drawing conclusions to answer the questions asked at the beginning of the project. Nevertheless, sometimes a previously established goal of the study needs to be changed to some extent, for instance when unforeseen obstacles arise (insufficient or unavailable data) or additional information arrives.

The last step, the *improvement assessment phase*, is performed in accordance with the goal of the study and on the basis of results from the impact assessment phase. This, in turn, is achieved by applying the computational procedure to the data in the inventory table.

### 5.3.2 Goal Definition and Scope

In the *goal definition and scope phase* the unambiguous and clear description of the goal of the study and its scope must be developed. The product (or service) to be assessed is defined, a functional basis for comparison in case of comparative analysis is chosen and, in general, the questions to be answered are established. The scope of the study sets requirements to the desirable level of detail.

The main issues to consider in this stage are:

- Purpose of the study: Why is the analysis being performed? What is the end use of the LCA? To whom are the results addressed?
- Specify the product to be investigated (functional unit).
- Scope of the study: depth and breadth (system boundaries).

As far as the *LCA end use* is concerned there are several basic possibilities:

- Product or process improvement.
- Product or process design.
- Publication of information on the product.
- Granting of an eco-label.
- Exclusion or admission of products from or to the market.
- Formulation of company policy (purchasing, waste management, product range, how to invest the money).

The intended audience is especially important to consider when preparing the presentation and communication of results. An LCA may be addressed to scientists, environmentalists, NGOs, the public (media, consumers). The manner of presenting the results should be tailored to meet their needs.

### 5.3.3 The Functional Unit

An LCA of a product must have *clearly specified functions* to be assessed. If, for instance, the product is a washing machine, it is important to describe its performance characteristics. These state what minimum quality standards the washing machine must meet: the degree of cleanliness and the degree to which clothes should be dried, how long the machine should work and how frequently it is to be used, the amount of clothes that can be washed at one time, etc. That is, it is important to define a function of a product rather than a product itself. The measure of performance which the system delivers is called a functional unit. The functional unit provides a reasonable point of reference when comparing different products.

Two products, A and B, may have different performance characteristics even though they fulfil the same function. An illustrative example is the comparison of different kinds of milk packaging, already discussed above. Two possible alternatives are: a milk carton and a returnable glass bottle. A glass bottle can be used ten or more times, whereas a milk carton can be used only once. On the other hand, a milk carton does not need washing and additional transportation. When comparing one carton and one bottle we could conclude that carton is the environmentally best choice. If the functional unit of the two packages is established, however, the analysis are not distorted by unfair assumptions.

Considered for example, that the packaging for 10 litres of milk could be a functional unit. In this case we have to com-

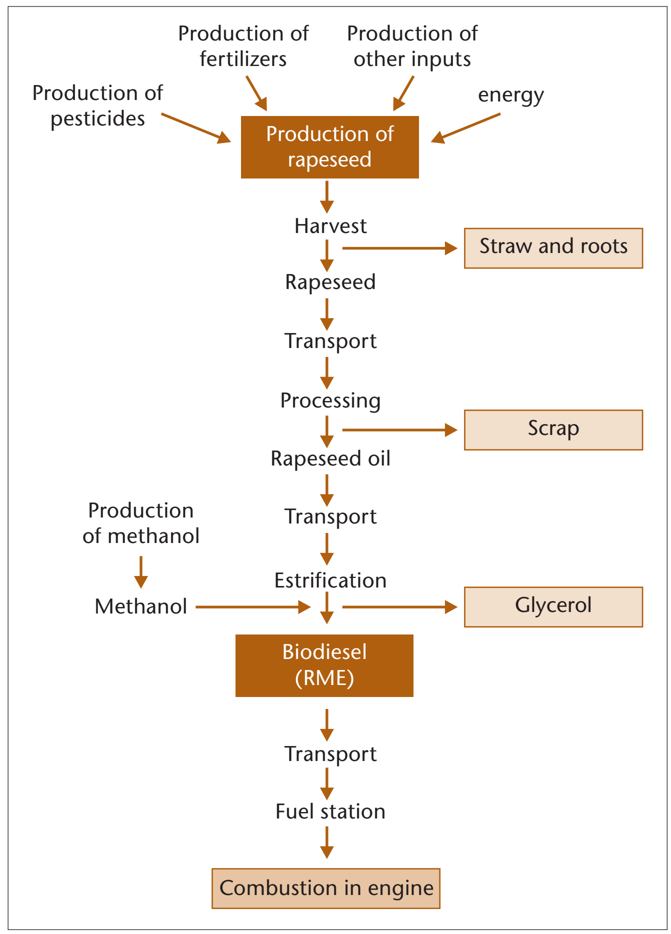



**Figure 5.3** *Process tree of the production and use of biodiesel [Hillary, 1995].*

pare 10 milk cartons to 1 bottle and 9 washings (assuming 9 return trips of the bottle).

Another example of a functional unit is when one wish to compare different anti-corrosive paints used for protecting a metal surface. The functional unit in this case might be the amount of paint which covers a certain surface for a certain time , e.g. 1 $m^2$ painted for 2 years. We then compare the different properties of the paints, the lifetime of coating, and the ability to cover a specified surface instead of the amount of paint.

### 5.3.4 System Boundaries

The next vital task in the goal and scope definition step is to define *system boundaries*. The necessity of defining system boundaries results from the fact that the main technique applied in any LCA is *modelling*. A function fulfilled by the product is represented by a model of the complex technical system. This consists of subsequent processes required to produce, transport, use and dispose of a product. The model is graphically illustrated by a process tree (a process flow chart) (Figure 5.3) and is used in the inventory analysis. Moreover, models of environmental mechanisms are created to translate inflows and outflows from the life cycle into the environmental impacts they may contribute to. For example, $SO_2$ emissions could increase acidity. This, in turn, can cause soil and water impairment, influence the quality of the ecosystem, deteriorate the living condition for animals and plants, etc. Such models are the basis for the impact assessment phase.

A model, by its definition, is a representation of reality but at the same time it is a simplification of reality. It means that the reality must be distorted to some extent in a model. On the other hand, one cannot avoid this problem. The system without simplifications is too complex to analyse. If a product system should include all the processes "from cradle-to-grave" one has to follow each inflow or outflow. This include, for example, crude oil, solar energy, iron ore from the environment, and all final waste released to the environment, i.e. emissions to air, water, soil, radiation. As a result the process tree would be practically endlessly branched.

Product systems are usually interconnected in a complex way, and it is impossible to isolate a single life cycle of a product without coming up against life cycles of other products. Thus e.g. in an LCA on glass bottles, trucks are used for transportation, so life cycle of a truck should be involved into the LCA. In the life cycle of the truck, steel is used to produce many parts of the vehicle, coal is needed to produce steel, steel is transported by trucks, etc.

This phenomenon is called *endless regression*.

To avoid such a problem the boundaries of the system must be defined. The system under study has to be separated from the environment as well as from other products and systems.

The typical question when defining the system boundaries is whether to include *the production of capital goods* or not. In a majority of LCAs capital goods, e.g. equipment of a workshop, are neglected. This assumption does not lead to important distortions of the final LCA outcome. In some cases, however, neglecting capital goods significantly underestimates environmental burdens. This applies to, for example, electricity production. It has been shown, that the production of capital goods constitutes about 30% of the total environmental impact resulting from an average generation of electricity.

Another common problem is presented by agricultural areas, which can be seen as a part of nature or as a part of the production system. For instance pesticides can be treated as emissions if agricultural areas are a part of nature. Otherwise (when agricultural areas are seen as a part of an economic system) only the part of pesticides, which leaves, a field somehow (evaporate or are accidentally sprayed outside) are perceived as emissions. The rest, which are not released to the environment, remains a part of a system.

A similar problem – which substances should leave the life cycle – concerns dumping waste. It can be regarded as final waste released to the environment or the start for long-term waste processing.

To narrow down the system boundaries, one uses *cut-off rules*. Thus if the mass or economic value of the inflow is lower than a certain percentage (a previously set threshold) of the total inflow it is excluded from further analysis. The same applies when the contribution from an inflow to the environmental load is below a certain percentage of the total inflow.

Carefully and properly specified goals and scope help to develop the model of the product in such a way that the simplifications and thus distortions have only an insignificant influence on the results. This is vital for getting reliable answers from an LCA. This challenging task undoubtedly depends to some degree on subjective decisions and requires a lot of experience.

## 5.4 Inventory Analysis and Allocation

### 5.4.1 Inventory Table

The inventory phase is the core of an LCA and is a common feature of any LCA. During this phase all the material flows, the energy flows and all the waste streams released to the environment over the whole life cycle of the system under study are identified and quantified. The final result of the inventory analysis is an inventory table. The inventory phase has four separate sub-stages:

- Constructing a process flow chart (so-called process tree).
- Collecting the data.
- Relating the data to a chosen functional unit (allocation).
- Developing an overall energy and material balance (all inputs and outputs from the entire life cycle) – an inventory table.

To develop a life cycle it is best to start from the product itself and then follow all upstream and downstream life stages.

**Table 5.2** *Selected items in an inventory table for the production of 1 kg of PVC derived from SimaPro.*

| No | Substance | Compartment | Unit | Total |
|---|---|---|---|---|
| 1 | Air | Raw material | g | 220 |
| 2 | Barrage water | Raw material | kg | 99 |
| 3 | Baryte | Raw material | mg | 82 |
| 4 | Bauxite | Raw material | mg | 440 |
| 5 | Bentomite | Raw material | mg | 32 |
| 6 | Clay minerals | Raw material | mg | 9 |
| 7 | Coal | Raw material | g | 135 |
| 8 | Crude oil IDEMAT | Raw material | g | 400 |
| 9 | Dolomite | Raw material | mg | 2 |
| 10 | Energy (undefined) | Raw material | MJ | 113 |
| ⋮ | | | | |
| 22 | $Cl_2$ | Air | mg | 2 |
| 23 | CO | Air | g | 2.3 |
| 24 | $CO_2$ | Air | kg | 2 |
| 25 | $C_xH_y$ | Air | g | 19 |
| 26 | Dust | Air | g | 29 |
| ⋮ | | | | |
| 36 | Acid as $H^+$ | Wastewater | mg | 48 |
| 37 | BOD | Wastewater | mg | 850 |
| 38 | Calcium ions | Wastewater | mg | 47 |
| 39 | Cl | Wastewater | g | 37 |
| 40 | COD | Wastewater | mg | 76 |
| 41 | $C_xH_y$ | Wastewater | mg | 26 |
| 42 | Detergent/oil | Wastewater | mg | 49 |
| ⋮ | | | | |
| 60 | Mineral waste | Solid waste | g | 42 |
| 61 | Plastic production waste | Solid waste | mg | 440 |
| 62 | Slag | Solid waste | g | 9.4 |
| 63 | Unspecified | Solid waste | mg | 9 |
| 64 | Occupied area as industrial area | Non material (land use) | $m^2$ | 400 |

This makes the LCA work systematic. Possible *upstream stages* are: extraction and production of raw materials, production of components (intermediates, semi-finished products, different parts), production of auxiliary materials (such as solvents, catalysts, etc.) and eventually production of the product itself. Among *downstream stages* are: use of the product, waste handling, processes of recycling and reuse if needed. Additionally, between all these processes, usually transport is needed and similarly the production of the energy carriers (electricity, steam) occurs along with almost all processes and life stages. A result of this step is illustrated by the process tree of the production of biodiesel (Figure 5.3), [Hillary, 1995].

On the basis of such a process tree, more detailed data is collected as required by the previously defined goal and scope (required level of details). All these actions have the same goal, namely to obtain a list of all inputs (materials consumed) and outputs (emissions) connected with the life cycle of the product. The data should be quantitative and are used to build an *inventory table*. An example of an inventory table for production of PVC is shown in Table 5.2. Note that this example of an inventory table is significantly abridged (it contains 27 out of 64 items).

To obtain such a table one should link the data describing the processes involved to produce the functional unit (e.g. how much $CO_2$ is released in conjunction with the production of 10 milk cartons).

### 5.4.2 Allocation

Very often a process fulfils two or more functions or gives two or several of usable outputs. They are *multi-output processes*. Then we have to determine which part of the total emissions and material consumption should be attributed to each specific product. The same applies to *multi-input processes*. Petrol production can serve as an example of a multi-output process. It provides several products in fractional distillation of crude oil: not only petrol but also kerosene, diesel oil, and mazout. The question is how to divide emissions and resource consumption over the petrol itself. An example of a multi-input process is a plastic bag. When performing an LCA for a plastic bag, we assume that at the end of its life cycle it is incinerated. However, there are many other products incinerated at one time. To what extent is the bag responsible for chemicals emitted from the incineration plant?

The problem of how to divide emissions and material consumption between several product or processes is called *allocation*. Several methods have been developed to deal with allocation.

*Substitution of allocation* – no allocation in fact. As allocation always require more or less subjective decisions, ISO recommends to avoid allocation if possible. This can be done by extending the system boundaries i.e. by including processes that would be needed to make the same by-product in the conventional way.

As an example, we can imagine a process in which a usable quantity of steam is produced as an additional output. It can be used to avoid the production of steam by more conventional means. This is an additional gain resulting from the process associated with the analysed product. This fact should be reflected in the main product's environmental profile. Then the environmental load of the avoided steam production may be subtracted from the overall environmental burden of the process. In this way one can calculate the part of emissions and material consumption that the main product is responsible for, and the rest is ascribed to the steam. The material consumed and emissions released, from the traditional way of producing steam are subtracted. It is not always easy to say how the steam would be produced alternatively, i.e. what a conventional method of steam production actually is.

Another typical example is electricity production in conjunction with waste incineration. The main purpose of this process is waste utilisation, but the simultaneously generated electricity is an additional benefit.

*Allocation based on natural causality* – in other words depending on one's common sense. In cases of combined waste incineration, $SO_x$ emissions should be allocated in relation to the S-content of different products, i.e. the more sulphur a certain product contains the more it is responsible for emissions of sulphur oxides. If a fraction of waste does not contain any sulphur, one may say it is not responsible for releasing sulphur oxides. Regrettably, there are plenty of examples of allocation problems, which this principle cannot solve.

*Allocation based on physical parameters such as mass, energy, etc.* Let us consider two usable products in a sawmill: wooden boards, as a main product, and sawdust as a by-product. When performing an LCA of wooden boards, an allocation problem will arise. An appropriate part of the environmental impact of the boards themselves can be derived directly from mass balance between outputs. If, for example, 40% of the total mass of the wood processed gives the sawdust, one can ascribe 40% of the environmental load to sawdust. Another example is naphtha cracking. Note that if this rule were applied in case of allocating steam, it would lead to ambiguous results since the mass of the steam is incomparably smaller.

*Allocation based on economic values (prices).* This principle is analogous to the previous one except that here economic values are the criteria. If, in the example of the sawmill, the sawdust contributes 20% of the value generated by the sawmill, one can allocate 20% of the environmental load to this by-product. Usually the main product is the most valuable, and has the highest price. By applying this method, the product for which the process is carried out is the most responsible for the total environmental burden. Prices, however, tend to change in time. Consequently the economic situation may influence an LCA although the environmental profile of a process itself remains the same.

*Arbitrary allocation.* The contribution of each co-product in the overall emissions and material consumption can be also imposed arbitrarily, e.g. equally for each product, 100% of emissions to one product, or any other random distribution.

### Allocation Techniques

- Substitution of allocation.
- Natural causality allocation.
- Allocation based on physical parameters.
- Allocation based on economic values.
- Arbitrary allocation.

## Study Questions

1. Give your own definition of LCA.
2. For what is LCA needed?
3. Which are the differences between quantitative and qualitative LCA methods.
4. What is a goal definition and scope of an LCA?
5. How should you define a functional unit? Will we obtain the same LCA results for product treated as different functional units? Give examples.
6. Which are the difficulties to decide on systems boundaries? Give example of cut off rules.
7. Define system boundaries for a simple product.
8. Write a simple process tree.
9. Which are the methods for allocation, both upstream and downstream?
10. Make an inventory analysis for a spoonful of tea.

## Abbreviations

| | |
|---|---|
| CBA | Cost Benefit Analysis. |
| EIA | Environmental Impact Assessment. |
| EM | Environmental Management. |
| EPS | Environmental Priority Strategies. |
| ERA | Ecological Risk Assessment. |
| LCA | Life Cycle Assessment. |
| LCM | Life Cycle Management. |
| MET | Materials Energy Toxicity. |
| MFA | Material Flows Analysis. |
| MIPS | Material Input Per Service unit. |
| NGO | Non Governmental Organisations. |
| RFM | Red Flag Method. |

## Internet Resources

Society of Environmental Toxicology and Chemistry

http://www.setac.org
http://www.setac.org/htdocs/who_intgrp_lca.html

ISO organisation

http://www.iso.org/

PRé Consultants Life Cycle Assessment

http://www.pre.nl/life_cycle_assessment/default.htm

US Environmental Protection Agency
Life-Cycle Assessment – LCAccess

http://www.epa.gov/ORD/NRMRL/lcaccess

Life Cycle Assessment Links

http://www.life-cycle.org/

UNEP environmental management
tools Life-Cycle Assessment

http://www.uneptie.org/pc/pc/tools/lca.htm

European Environment Agency's guide to approaches, experiences and information sources of LCA

http://reports.eea.eu.int/GH-07-97-595-EN-C/en

# 6 Life Cycle Impact Assessment

## 6.1 Impact Assessment Systems

### 6.1.1 The Components of Impact Assessment

A typical Life Cycle Assessment inventory table consists of a few hundred or more items. They might be grouped into categories: raw materials, emissions to air, water, soil, solid emissions, non-material emissions (noise, radiation, land use) etc. An inventory table is a basis for the next step of LCA – impact assessment.

On the condition that an inventory table contains relatively few items, an environmental expert can assess the life cycle without applying any mathematical procedures. In practice, however, such a situation hardly ever obtains. The data from an inventory table has to be processed to attain a higher level of *aggregation*. Ideally the aggregation process results in a meaningful single score. To achieve this, the ISO standards advise a four-step procedure (We will discuss each of these steps below.):

- Compulsory steps: classification and characterisation.
- Optional steps: normalisation and weighting.

### 6.1.2 Classification of Impacts

The first step to higher aggregation of the data is classification. Inflows and outflows from the life cycle are gathered in a number of groups representing the chosen impact categories. The inventory table is rearranged in such a way that under each impact category, all the relevant emissions or material consumption are listed (qualitatively and quantitatively). This procedure is illustrated in Figure 6.1.

The common source of uncertainty here is the lack of a universally accepted appropriate official list of environmental impacts to consider. Nevertheless, as a result of numerous already performed LCAs, a "standard", a list of environmental impacts that should be treated does exists. These are all broadly recognised environmental problems such as resource depletion, toxicity, global warming, ozone depletion, eutrophication, acidification, etc. The choice of impact categories is subjective. It should be adjusted to ensure good representation of the environmental burden caused by a product, as the outcome of the LCA strongly depends on the choice of impact categories. The list should, if possible, be made already as a part of the goal and scope definition. There are many other possible impact categories which may be important in some situations, especially in the local scale, and then should be included. Examples are radiation, final solid waste load, noise, smell, and landscape degradation.

Some outputs can be allocated to more than one category, e.g. $NO_2$ causes both acidification, eutrophication and toxicity.

**In this chapter**

**Table 6.1 Contribution to global warming from a product life cycle.** *Emissions, expressed as weight, are listed with their global warming potential (GWP) expressed as an equivalence factor which relates its GWP to that of carbon dioxide. The contribution to global warming can then be expressed as kg of carbon dioxide equivalents and summed.*

| Substance | Amount (kg) | GWP Equivalence factor | $CO_2$ (kg) |
|---|---|---|---|
| Methane | 0.001 | 11 | 0.011 |
| $CO_2$ | 25 | 1 | 25 |
| $N_2O$ | 5 | 270 | 1350 |
| $CH_2Cl_2$ | 0.0005 | 15 | 0.0075 |
| $CFCl_3$ | 0.00001 | 13000 | 0.13 |
| $CO_2$ - equivalents | | | 1375.1485 |

It ought to be emphasised that under the environmental impacts we in fact understand *potentials* for environmental impacts. We do not know if the emissions connected with a life cycle will really occur, and sometimes we do not know if the emissions that do occur cause the impacts. E.g. acid emissions may not cause damage if it is deposited on not so sensitive soil.

### 6.1.3 Characterisation – Equivalence Factors

In the previous step, substances contributing to the impact categories were taken from an inventory table and ascribed to a certain group. However, different substances among one group contribute differently to the impact category. During the characterisation step the relative strength of the unwanted emission is evaluated and contributions to each environmental problem are quantified. What is needed here is a single number for each category.

The computational procedure used for aggregating the data among one impact category may be explained by the example for global warming. The characterisation can be performed on the basis of environmental models, which allow us to compare different substances contributing to the same environmental problem. This is done by applying so-called *equivalence factors*. An equivalence factor indicates how many times more a given compound contributes to a problem in comparison to a chosen reference substance. In case of global warming $CO_2$ is chosen to be the point of reference. All the other substances causing an enhanced greenhouse effect are given a coefficient indicating how many times more or less these compounds contribute to the effect. For example, methane has an equivalence factor of 11, which means that 1 kg of methane causes the same greenhouse effect as 11 kg of carbon dioxide. The result is expressed in the equivalent amount of $CO_2$.

When the equivalence have been calculated all the figures in the impact category have a common unit and can be added up.

Let us consider a hypothetical product, whose entire life cycle results in the emission of a certain amount of greenhouse gases. These can be derived from the inventory table in the classification step and are as following: 1 g of methane, 25 kg of $CO_2$, 5 kg of $N_2O$, 0.5 g of $CH_2Cl_2$ and finally 0.01 g of $CFCl_3$. All of them are given equivalence factors used for multiplying adequate amounts of released gases. After multiplication all emissions are expressed in the same unit, kilograms

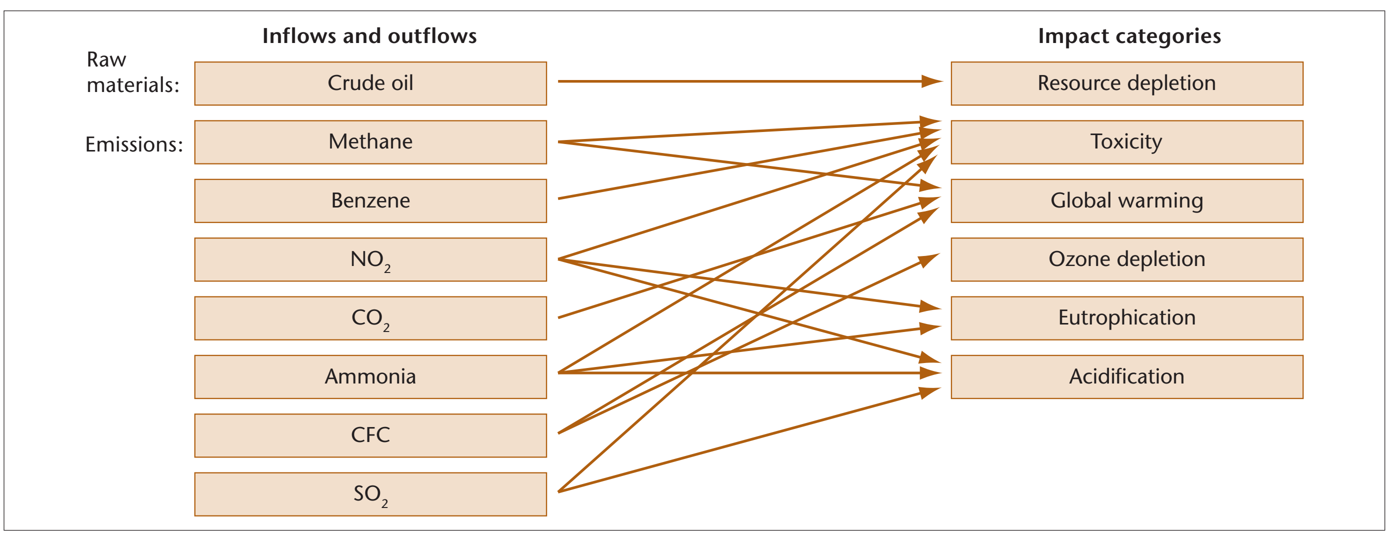



**Figure 6.1 Relations between emissions and impact categories.** *To the left are raw materials used (top) and pollutants emitted (bottom) during the life cycle of a product. To the right are the impact categories to which these emissions contribute. The figure illustrates that one emission may contribute to several impacts, and that several emissions contribute to the same impact.*

of equivalent amount of $CO_2$ and can be added up giving one number. The described computational procedure can be traced in Table 6.1.

As can be viewed in the table the overall contribution to global warming in this example equals ca. 1,375 kg of equivalent $CO_2$.

Characterisation is easy if all substances contributing to each impact category are known and a reference substance as well as equivalence factors have been defined. For many of the environmental impacts, the equivalence factors remain controversial with regard to the methodology by which they are calculated. This applies especially to the categories which are difficult to describe, e.g. "human health". Nevertheless, there are established equivalence factors for the main environmental problems (Table 6.2).

### 6.1.4 Environmental Profiles

The final result of the characterisation step is a list of potential environmental impacts. This list of effect scores, one for each category, is called the *environmental profile* of the product or service.

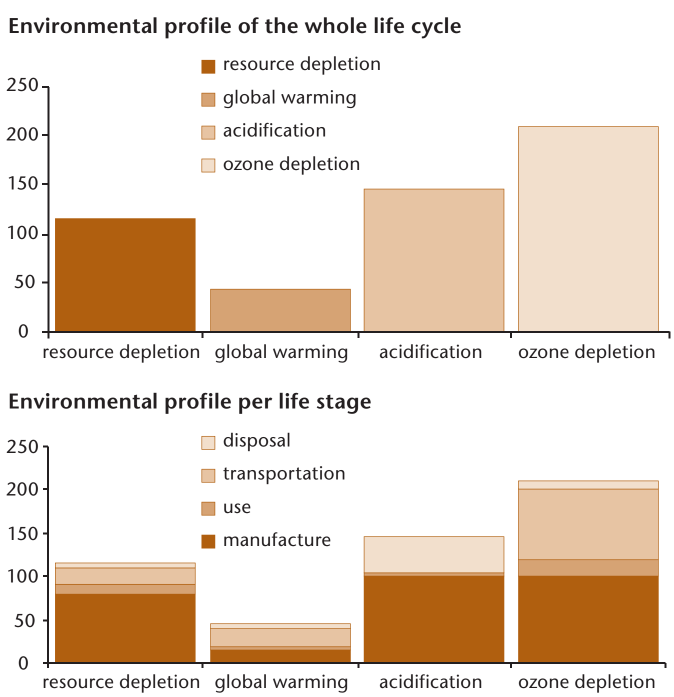



**Figure 6.2 Environmental profiles.** *The impact of a life cycle may be expressed as the sum of each kind of impact summed over the entire life cycle (above), or as the impact expressed separately for each life stage (below). In this life cycle four impacts are considered (resource depletion; global warming; acidification; and stratospheric ozone depletion), and four life stages (disposal (wasting); transportation; use; and manufacture) [Hillary, 1995].*

**Table 6.2 Equivalence factors for environmental impacts.** *The contribution to an environmental impact is calculated for any substance if an equivalence factor is available.*

| Classification of environmental impact | | Equivalence factor and reference substance |
|---|---|---|
| Ozone depletion | Ozone Depletion Potential | CFC-11 equivalents |
| Acidification | Acidification Potential | $SO_2$ equivalents |
| Eutrophication | Eutrophication Potential | Phosphate equivalents |
| Photochemical smog creation | Photochemical Ozone Creation Potential | ethylene equivalents |

The two graphs in Figure 6.2 show environmental profiles for a virtual product. These are sets of four single scores, one for each of four impact categories: resource depletion, global warming, acidification and ozone depletion. The second way of presenting the environmental profile is more meaningful. It divides single scores between four life stages: manufacture, use, transportation and disposal. It allows us to identify immediately the life cycle phases which have a significant environmental impact. For example manufacturing contributes greatly to resource depletion.

## 6.2 Normalisation

### 6.2.1 Normalised Effects

The results from the characterisation step cannot be compared since they are usually presented in different units ($CO_2$eq., $SO_2$eq., CFC-11eq, etc.). A procedure to allow us to compare impact categories among themselves is therefore carried out. This is called *normalisation*.

Normalisation is performed to make the effect scores of the environmental profile comparable. The *normalised effect score* is the percentage of a given product's annual contribution to that effect in a certain area:

$$\text{Normalized effect score} = \frac{\text{annual contribution to that effect in a certain area}}{\text{effect score for a given category}}$$

From the normalised environmental profile one can conclude, for instance, that product X constitutes 1% of all $CO_2$eq. attributed to one inhabitant per year. Consequently, we can say, for example, that a life cycle of a product contributes more to global warming than to ozone depletion. The figures do not indicate, however, which impacts are of the highest priority, i.e. one cannot say that global warming is a more serious environmental problem than ozone depletion nor the other way around. The environmental profile is only put in a broader context, which makes the interpretation easier.

The lack of relevant figures representing annual contributions to environmental problems is the main difficulty in the normalisation step.

### 6.2.2 Calculating an Environmental Profile

The principle of a normalisation is illustrated by the diagram below (Figure 6.3). It shows a computational procedure for an environmental profile of a coffee machine in Belgium [SimaPro Manual, 2000]. The entire life cycle of the coffee machine results in the following emissions: 6.1 kg of equivalent $CO_2$ (for global warming), 56.2 g of equivalent $SO_2$ (for acidification), 2.88 g

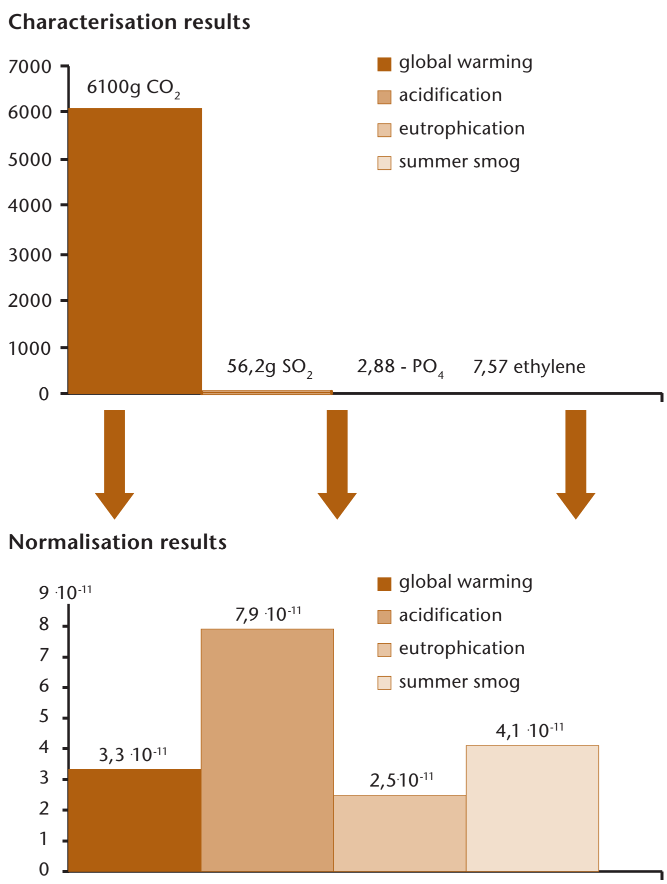



**Figure 6.3 Normalisation of impacts from the life cycle of a Belgian coffee machine.** *The impact of the life cycle contains four impacts, expressed as carbon dioxide equivalents (global warming), $SO_x$ equivalents (acidification); phosphate equivalents (eutrophication) and ethylene equivalents (summer smog formation) (top diagram). Normalisation consists of the division of these emissions with the total emission in each category over an entire year in the country. The resulting relative sizes of the impacts are in the order of 2-8 hundred billionths ($10^{-11}$) of the total annual impacts.*

**Table 6.3 Total contribution to four impact categories in Belgium.** *The total emissions contributing to the four given impact categories in Belgium, expressed as equivalents of carbon dioxide, sulphur oxides, phosphate and ethylene emitted over one year [Hillary, 1995].*

| | |
|---|---|
| Global warming | $1.85*10^{14}$g $CO_2$/year |
| Acidification | $7.09*10^{11}$g $SO_2$/year |
| Eutrophication | $1.17*10^{11}$g $-PO_4$/year |
| Summer smog | $1.84*10^{11}$g ethylene/year |

of equivalent $-PO_4$ (for eutrophication) and 7.57 g of equivalent ethylene (for summer smog). All these numbers are divided by the amount of adequate substance emissions in Belgium over a period of one year gathered in Table 6.3. It allows us to achieve a normalised environmental profile consisting of four numbers (one for each impact category) having a common unit: a year, as can easily be seen from the graphs. A normalised environmental profile enables the practitioner to compare the single scores. Normalisation also changes the relations between results for different impact categories. Although global warming has definitely the highest single score as for the absolute value (characterisation), after normalisation we can conclude that the largest environmental impact of the coffee machine is acidification.

## 6.3 Weighting

### 6.3.1 Comparing Impact Categories

In order to obtain a single score representing the environmental impact of a product, we need further aggregation of the data. *Weighting (valuation)* is the step in which the different impacts categories are weighted so that they can be compared among themselves, i.e. the relative importance of the effects is assessed.

In comparative analysis the prime goal is to find out which one of the products fulfilling the same function is the best option for the environment.

In the example in Figure 6.4 product B has the smallest single scores for each impact category so it is environmentally the best. But then let us compare then products A and C now. Product A is better in terms of global warming, resource depletion and ozone depletion but at the same time it is worse for acidification. It is impossible to indicate which alternative is better, A or C, because it depends on the impact category! To solve this problem, the relative importance of the different impact categories has to be assessed; a hierarchy of impact categories has to be defined. If acidification is given a higher priority, then the product C will be more environmentally friendly than A. If ozone depletion is assumed to be the most serious environmental problem, product A will be more environmentally sound than C.

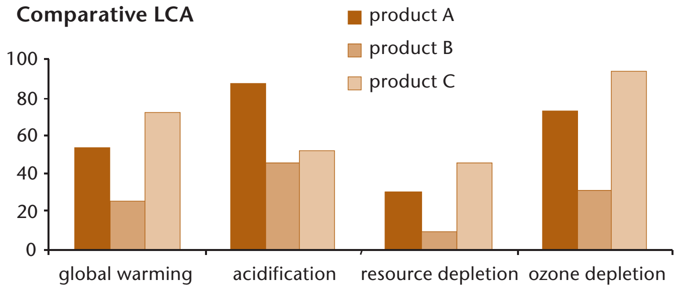



**Figure 6.4 Comparing impacts of life cycles from different products.** *Four impacts from three different products, called A, B and C expressed as relative values.*

## 6.3.2 Environmental Index

How to establish such a set of preferences and priorities? This is a still subjective process although much effort has been spent in recent years to work out a scientific basis for weighting, i.e. *weighting principles*. Ranking impact categories in terms of their environmental impact makes clear distinction between the weighting and all of the previous phases. The latter use empirical knowledge of environmental effects and their mechanisms, while the weighting relies mainly on preferences and social values. In practice, weighting is performed by multiplying a normalised environmental profile by a set of *weighting factors*, which reflect the seriousness of a given effect.

One of the ready-made methods, Eco-indicator 95, can serve an example of a defined set of weighting factors (Table 6.4).

As it can be concluded from the table, the highest priority is given to ozone layer depletion and emissions of pesticides.

If each impact category is provided with a factor according to its environmental significance, an environmental profile can be expressed in a single *environmental index*. An environmental index is a sum of the numbers, which a weighted environmental profile consists of. Once the environmental indices are calculated, comparisons of products are easy. Let us assume that product A is represented by an environmental index of 5 and product B has an environmental index of 10. One can conclude that A is twice as environmentally friendly as B. The main difficulty lies, however, in the fact that there is no broadly accepted methodology for establishing weighting factors. For the time being it is difficult to rank environmental problems without running the risk of criticism.

## 6.3.3 Weighting Principles

Some successful attempts have been made to devise weighting principles. The details of these are found in Box 6.1. In short they are as follows.

A *Panel of experts* can provide a qualitative analysis which uses weighting without weighting factors. Instead of applying the computational procedure the rating is performed by the panel of experts. The major disadvantage of this approach is its poor reproducibility – the results will often remain controversial and open to discussion.

### Determination of Weighting Principles

- Panel of experts
- Social evaluation
- Prevention costs
- Energy consumption
- Distance-to -target principle
- Avoiding weighting

The so-called *Social evaluation* is the basis of the EPS (Environmental Priority Strategy) system. EPS is designed to be used internally as a tool supporting product development within a company. It is there to assist designers and product developers in finding which of two product concepts is preferable in environmental terms.

*Prevention costs*, are costs of preventing or combating the negative changes in the environment with the aid of technical means. The principle of this approach is simple: the higher the prevention costs, the higher the seriousness of the impact.

*Energy consumption.* This approach is analogous to the previous one, except that in this case the overall energy needed to prevent emissions consumption is used as an indicator. The higher the energy consumption, the higher the seriousness of the impact.

The *Distance-to-target principle* is based on the assumption that the seriousness of an effect can be related to the difference between the current and target values [Goedkoop, 1995]. It should be clear that the choice of the target value is crucial. Much thought has also been given to the choice and development of the target values.

**Table 6.4** *Weighting factors used in Eco-indicator 95.*

| Impact category | Weighting factor |
|---|---|
| Greenhouse | 2.5 |
| Ozone layer | 100 |
| Acidification | 10 |
| Eutrophication | 5 |
| Heavy metals | 5 |
| Carcinogens | 10 |
| Winter smog | 5 |
| Summer smog | 2.5 |
| Pesticides | 25 |

## Box 6.1 Principles of Weighting

**Panel of experts:** This is a qualitative analysis which uses weighting without weighting factors. Instead of applying the computational procedure the rating is performed by a panel of experts. The major disadvantage of this approach is its poor reproducibility – the results will often remain controversial and open to discussion. As the weighting is based on one's point of view, another panel of experts could arrive at different conclusions. For the sake of high costs of the analysis based on a panel of experts, it is rather unlikely to apply this approach in the product improvement and development within companies.

**Social evaluation:** This principle is a basis in the EPS system (Environmental Priority Strategy). The EPS system is designed to be used internally as a tool supporting product development within a company. It is supposed to assist designers and product developers in finding which of two product concepts is preferable in environmental terms. Before the system can be used outside the gate it must be clearly described and documented. The principle applied in the EPS system is illustrated in Figure 6.5 [Goedkoop, 1995].

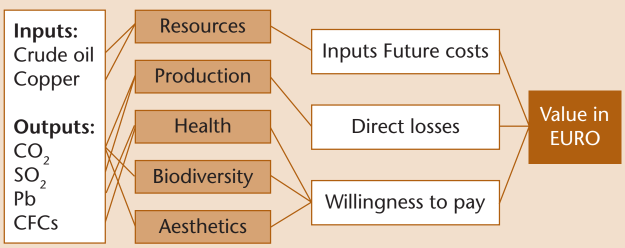



**Figure 6.5** *Principle of EPS system.*

The damage to the environment is expressed in financial terms. The impairment of human health, for instance, can be expressed as the costs that a society is prepared to pay for health care. Other kinds of damage caused to the environment are considered among so-called safeguard subjects which are:

- Resources: expressed as future costs which are the costs of extraction of the "last" raw material. In other words, future extraction costs are estimated. The higher the costs, the higher the significance of environmental problems resulting from consumption of a given raw material. Future costs can be also seen as costs of the production of an alternative material, which is suppose to substitute for the unrenewable one in the future. It means that where it is possible, production costs of alternative fuels are used. For example, costs of oil extraction are converted into the price of rape seed oil production; similarly wood is used to replace coal. Nevertheless, the approach is not yet fully developed. No attempt is made to use alternatives to minerals although in many applications of copper, for example, other materials such as aluminium or glass fibre (much less scarce) could be used instead.
- Production: direct losses – expected reduction in agricultural yields and industrial damage (caused by e.g. corrosion).
- Human health: expressed, as has been previously stated, as willingness to pay for the human health impairment (combating diseases, number of deaths, the extinction of species as well as the impairment of natural beauty are examined).
- Biodiversity
- Aesthetic values

To sum up, there are three ways of expressing the damage to the environment in financial terms among safeguard subjects (Figure 6.5):

1. Future costs (raw material depletion).
2. Direct losses (production).
3. Willingness to pay (health, biodiversity, aesthetic values).

**Prevention costs**, i.e. costs of preventing or combating the negative changes in the environment with the aid of technical means. The principle of this approach is simple: the higher the prevention costs, the higher the seriousness of the impact. However, a critical point arises in this approach when calculating prevention costs. There are many different ways to deal with emissions. They are more or less effective and more or less expensive. Before the weighting factors can be established, a method of prevention and the required purity have to be accurately defined. In consequence the outcome depends on a large number of technological factors.

**Energy consumption:** This approach is analogous to the previous one, except that in this case the overall energy needed to prevent emissions consumption is used as an indicator. The higher the energy consumption, the higher the seriousness of the impact. The total energy consumption is calculated as a sum of the three variables:

1. Energy consumption.
2. Carbon dioxide emissions – converted into the energy needed to purify exhaust fumes.
3. Water consumption – converted into the energy needed to purify sewage.

Although the calculations in this case are not based on economic terms any more, the main uncertainty remains. The outcome depends significantly on the technical method used for purification of exhaust fumes or sewage as well as on the degree to which an impact has to be counteracted.

**Distance-to-target principle:** This method is based on the assumption that the seriousness of an effect can be related to the difference between the current and target values [Goedkoop, 1995]. It should be clear that the choice of the target value is crucial. Much thought has also been given to the choice and development of the target values.

The procedure can be expressed in the following equation (1):

$$I = \sum_i W_i * \frac{E_i}{N_i} * \frac{N_i}{T_i} = \sum_i W_i * \frac{E_i}{T_i}$$

where:

I indicator value.
$N_i$ current extent of the regional (in Eco-indicator 95 European) effect i, or the normalisation value.
$T_i$ target value for effect i.
$E_i$ contribution of a product life cycle to an effect i.
$W_i$ subjective weighting factor which expresses the seriousness of effect i.

The subjective weighting factor is entered in this phase to make corrections in the event that the distance-to-target principle does not sufficiently represent the seriousness of an effect. When this factor is introduced the distance-to-target principle seems to lose much of its value because there is an unlimited degree of subjectivity.

It will be noted that the normalisation value N is omitted from this equation. This is a more or less coincidental effect that is more to do with the formulation of the different terms. The term N/T, for example, can be written as a reduction factor F. The reduction factor is equal to the weighting factor, as can be seen from the above. In that case the equation (2) becomes:

$$I = \sum_i W_i * \frac{E_i}{N_i} * \frac{N_i}{T_i} = \sum_i W_i * \frac{E_i}{T_i} * F_i$$

This means either that the target value must be known (for equation 1) or the current level and the reduction factor (for equation 2). In practice (case studies) it became apparent that it is much easier to determine the reduction factor plus the current value than the target level. The reduction factor can be directly seen as a weighting factor. The use of equation 2 makes the weighting much clearer because, in accordance with the SETAC method, the effect of the normalisation stage must first be apparent and then the effect of the weighting. This has resulted in a great deal of attention having to be paid to the retrieval of current values.

Before using this method the following questions should be answered:

- What is the basis for defining the target level?
- What effects are evaluated, and how are these defined?
- How can effects that cause different types of damage be assigned an equivalent target value?

Objectives for environmental pollution reductions are a compromise between scientific, economic and social considerations. For a more scientific approach, a number of alternatives are available:

1. Zero as the target value for the effect. A problem then arises when using the equation derived above.
2. No effect level. This is a low value in which no demonstrable damage to the environment occurs, a level which cannot be clearly defined.
3. A low damage level. This is a level where demonstrable but limited damage occurs.

The third option was chosen for practical reasons. In itself the choice is not as important if the damage levels per effect are well comparable. If all target values are doubled, all the reduction factors, thus all the weighting factors, will be halved. This has no relevance to the mutual correlations of the weighting factors.

The whole weighting method is shown schematically in the Figure 6.6.

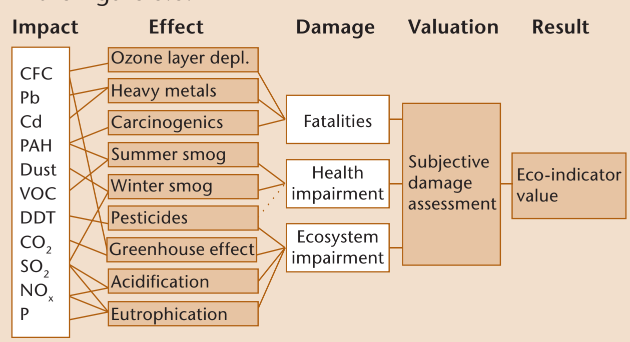



**Figure 6.6** *Schematic representation of the Eco-indicator weighting method [Goedkoop, 1995].*

**Avoiding weighting by using only one environmental effect**, namely energy consumption. This principle derives from the fact that energy consumption can be seen, in some cases, as an indicator of the total environmental pollution. Many harmful emissions are released in conjunction with the conversion of energy from fossil fuels and energy consumption can be seen as a good representation, at least for fossil fuel depletion. Since there is one variable taken into account, no weighting in fact is performed. Nevertheless, neglecting the other environmental impacts, which are not connected with production of energy, can significantly underestimate the environmental burden of a product. It means also that the overall environmental profile will be highly distorted because serious environmental problems such as ozone layer depletion and ecotoxicity are left out.

A number of European countries have formulated objectives for environmental pollution reductions. In general the objectives are a compromise between scientific, economic and social considerations. This can result in values being chosen that are very different from the scientifically defined value. An indicator that is based on politically determined target values refers not so much to environmental pollution as to conformity with policy decisions. This was not the aim of this method.

For a more scientific approach, a number of alternatives are available:

*Zero as the target value* for the effect. A problem then arises when using the equation derived (Box 6.1).

*No effect level.* This is a low value in which no demonstrable damage to the environment occurs. The problem is that such a level cannot be clearly defined. Taken literally, it means that at that level no single organism suffers even the slightest damage. Ecosystems are so complex that it is impossible to check this in practice.

*A low damage level.* This is a level where demonstrable but limited damage occurs. For example, impairment to the level of a few percent of a particular ecosystem or the death of a number of people per million inhabitants.

The third option was chosen for practical reasons. In itself the choice is not as important if the damage levels per effect are well comparable. If all target values are doubled, all the reduction factors, thus all the weighting factors, will be halved. This has no relevance to the mutual correlations of the weighting factors.

Finally one may *avoid weighting by using only one environmental effect*, namely energy consumption. This principle derives from the fact that energy consumption can be seen, in some cases, as an indicator of the total environmental pollution. Many harmful emissions are released in conjunction with the conversion of energy from fossil fuels and energy consumption can be seen as a good representation, at least for fossil fuel depletion. Since there is one variable taken into account, no weighting in fact is performed.

### 6.3.4 Weighting Triangle

As mentioned, the weighting phase in any LCA remains the most doubtful and controversial, because of the subjective assessment of environmental issues. The results may, however, be expressed in a less subjective way, when the weighting is analysed with aid of a so-called *weighting triangle* (Figure 6.7), [Goedkoop and Oele, 2001]. The triangle indicates to what extent the result of an analysis is dependent on weighting factors. This approach can be used if three damage categories are taken into account. The sum of the three weighting factors represents 100%, so let us assume that it equals 100. Then this figure can be distributed in different ratios between damage categories, e.g. 50 for human health, 40 for ecosystem quality and 10 for resource depletion. In other words, the ratings given in this way mean that the deterioration of human health is assessed to be most serious environmental problem, more serious than system quality and resource depletion. This set of weightings can be represented by a point in the triangle [Goedkoop and Oele, 2001].

The procedure can be applied for any combination of weighting factors. One might, for instance, decide that depletion of natural resources is the largest environmental concern. This can be shown as another point in the triangle. For each set of weighting factors the products studied by LCA are compared.

The importance of the weighting factors are clearly shown. For a certain set of weighting factors, product A may be better whereas, for another set of weighting factors, it is product B. The outcome is influenced by the weighting principle. In this case two separate areas in the triangle will appear: in the first

**Hint**

In line with the Eco-Indicator approach, weighting according to the Distance-to-Target method seems to be most appropriate for this component of LCA analysis.

$W_{EQ}$ Weighting factor for the damage to ecosystem quality
$W_{HH}$ Weighting factor for the damage to human health
$W_R$ Weighting factor for the damage to energy resources
$W_{EQ} + W_{HH} + W_R = 100\%$

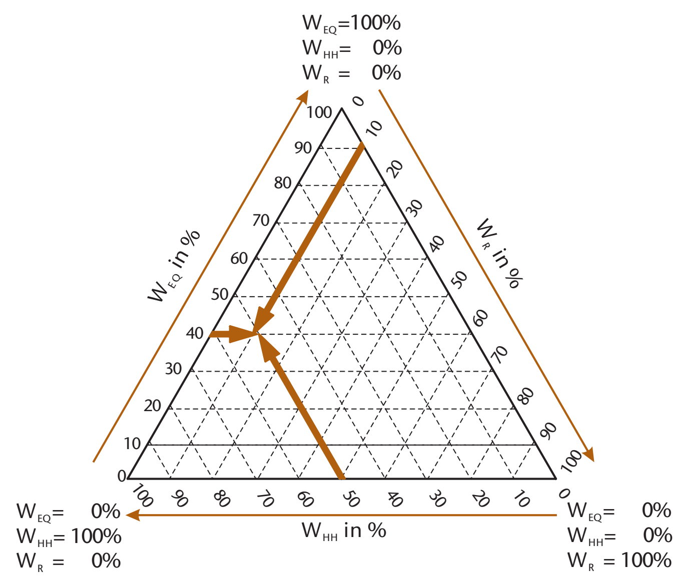



**Figure 6.7** *The weighting triangle.*

one product A is superior to B in environmental terms, and in the other product B is preferable. The line between these two areas is called the line of indifference and represent all the weighting sets for which product A and B have the same environmental indexes, i.e. the same environmental loads (Figure 6.8), [Goedkoop and Oele, 2001].

It should be stressed that if a product has a lower environmental index regardless of established priorities, the whole triangle is of the same colour and the line of indifference lies outside.

## 6.4 Improvement Assessment

### 6.4.1 Uncertainties in the Impact Assessments

Improvement assessment closing an LCA should thoroughly analyse all the results obtained during previous methodological stages and give answers to questions asked in the goal and scope definition phase. The possible ways to reduce the environmental burden of a product should be suggested and evaluated. In this phase a detailed report is also drawn up to present the results in the most informative way possible, suited to the intended audience. There are several issues to cover.

*Uncertainty.* The LCA methodology still has many weak points and strongly depends on the quality of the data, which frequently is extremely hard to obtain. All these factors must be highlighted when drawing conclusions from the analysis, not to mislead the audience. The conditions for receiving credible results should be unambiguously described. There are two main sources of uncertainty. First is the quality of the data – data often comes from different sources, estimates, assumptions, theoretical calculation, etc.. Secondly any LCA, includes subjective choices which cannot be avoided – uncertainty is part of the model, e.g. system boundaries, allocation rules, characterisation models. For products, which have long lifetimes, future events have to be predicted. These products will be disposed of in a few decades and the future waste treatment is uncertain. When drawing conclusions, one has to also

$W_{EQ}$ Weighting factor for the damage to ecosystem quality
$W_{HH}$ Weighting factor for the damage to human health
$W_R$ Weighting factor for the damage to energy resources
$W_{EQ} + W_{HH} + W_R = 100\%$

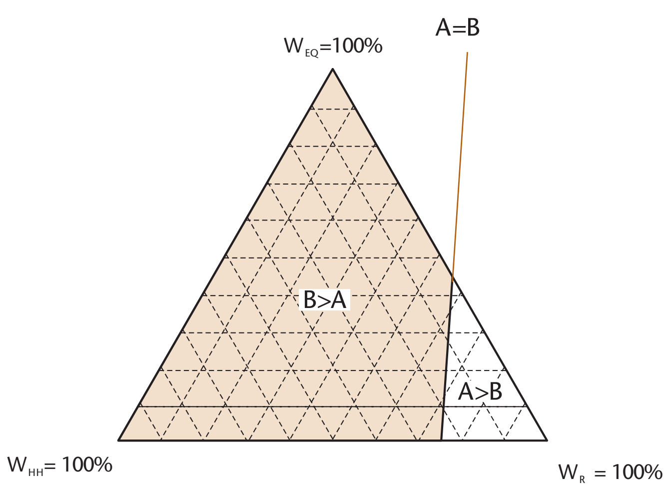



**Figure 6.8** *Areas of product B and A superiority in the weighting triangle.*

### Damage Categories (End points)

- Human Health.
- Ecosystem Quality.
- Resources.

### Example

Comparing two different ways of making coffee (SimaPro Manual, 2000); an ordinary gas stove to a coffee machine, with a plastic housing (model Sima), one can see that if the higher rating is given to "resource depletion" the coffee machine is more advantageous than the traditional gas stove. The traditional gas stove shows advantages for high priority of the "human health" damage category.

Life cycle: use of gas stove lower environmental load
Life cycle model Sima (plastic) lower environmental load

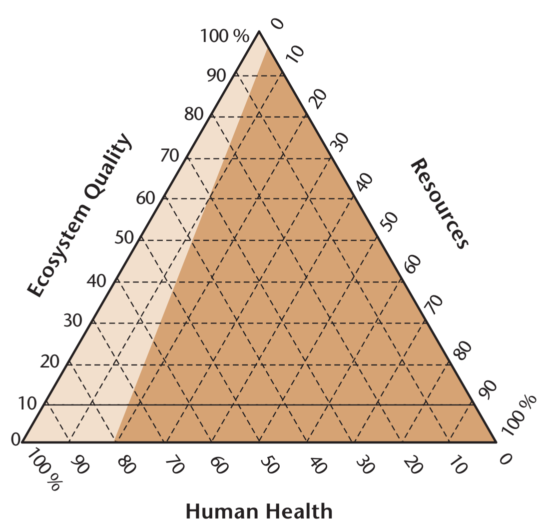



**Figure 6.9** *Areas of product B and A superiority in the weighting triangle.*

analyse the gap between the inventory table and the impact assessment method. Many items are neglected in classification and characterisation for the sake of the lack of sufficient data. Numerous emissions have not been given an equivalence factor since their influence on the environment is not known yet. It means that such items from the inventory table are neglected in further analysis.

A *sensitivity analysis* is made to check how stable the results are. It should be proved that input data and methodological choices do not influence the results of an LCA too much. If, however, the results turn out to be strongly sensitive to any step of the analysis, it should be reported and analysed in details. During sensitivity analysis the assumptions are changed and the LCA is recalculated and the outcomes are compared. In this way the critical points in an LCA are identified. The results of the sensitivity analysis indicate if general conclusions drawn from an LCA are stable and reproducible.

### 6.4.2 Which Process is Important

*Contribution analysis.* On numerous occasions an environmental profile of a product is moulded by 5 or even 1% of all processes involved in the life cycle. In other words, usually only a number of processes play a decisive role in the environmental profile of the product whereas all the rest can be neglected without any serious impact on the results. Contribution analysis is supposed to find the processes of the highest significance and determine their contribution in the environmental index. This information allows to significantly simplify a process tree and focus one's attention on its most important components.

*Identification and evaluation of possible actions.* If there is any suggestion of how to improve the environmental performance of a product, an LCA should be quantitatively performed for the improved product, which allows us to describe the potential benefits of the new product.

## Abbreviations

| | |
|---|---|
| CFC | Chloro Fluoro Carbon. |
| GWP | Global Warming Potential. |
| LCIA | Life Cycle Impact Assessment. |

## Study Questions

1. Classification of impacts: Make a short list of categories.
2. Develop your own impact and damage categories.
3. Explain why and how equivalence factors are used.
4. Describe how an environmental profile is calculated using normalisation.
5. Explain why weighting is used and what is an environmental profile.
6. List and describe the most important weighting principles. How are weighting factors determined?
7. Characterize the main drawbacks of weighting step in the entire LCIA.
8. Draw a weighting triangle and illustrate its use with one example.
9. Explain how a distance-to-target calculation is made.
10. Which step in LCIA is the most doubtful?

## Internet Resources

Eco-indicator 95, handleiding voor ontwerpers (in Dutch)

http://www.io.tudelft.nl/research/ dfs/idemat/Backgr/noh9510.doc

UNEP Sustainable Consumption – Life Cycle Initiative

http://www.uneptie.org/pc/sustain/lcinitiative/

Society of Environmental Toxicology and Chemistry (SETAC)

http://www.setac.org/htdocs/who_intgrp_lca.html

PRé Consultants, SimaPro LCA software

http://www.pre.nl

Environmental Business Information Center

http://www.environmental-expert.com/

Centre for Design – LCA Design

http://www.cfd.rmit.edu.au/

LCA studies and database

http://www.piranet.com/

LCA in Japan – An Inventory

http://www.gdrc.org/uem/lca/lca-japan.html

Tools for Environmental Analysis and Assessment

http://www.ecobalance.com/

# 7 Ready-made Methods for Life Cycle Impact Assessment

## 7.1 Semi-quantitative LCIA Methods

There are several different qualitative methods for conducting an LCA. When working with a *ready-made method* one needs to do the review of the life cycle of the product or service just as in a proper full scale LCA – agree of systems boundaries, allocations etc. The difference lies in the way in which the impact assessment is performed: different impact categories are taken into account, different environmental models and equivalence factors are used for the characterisation, different reference points are used during normalisation and different ways are used when conducting the weighting phase.

The ready-made methods, among others, include:

- EPS system (Environmental Priority Strategies in product design).
- EDIP/UMIP (Environmental Development of Industrial Products, in Danish UMIP).
- Eco-points.
- Eco-indicator.
- MIPS (Material Input per Service Unit).
- Ecological footprints.

There are several more than those listed. The Eco-indicator concept seems to be the most successful one in practical LCIA applications.

In the ready-made methods there is a straightforward way to aggregate the environmental impacts into a single index or a simple set of characterisation indicators, as in the Eco-indicator. This means that the environmental impacts are measured along the same scale, and they can simply be summed up. This scale is different for the different methods. It may for example be physical-chemical properties, surface area, or weight.

When the environmental impacts, emissions etc, has been listed one goes back to a table where all the different impacts are translated into the particular scale used to make a final impact assessment.

## 7.2 The Eco-indicator and Eco-points

### 7.2.1 The Eco-indicator Methodology

The eco-indicator was first introduced in 1995 as Eco-indicator 95 by Goedkoop and co-workers [Goedkoop, 1995] to provide engineers and designers with a simple method to estimate the environmental impact of proposed design solutions. It was thus in the first place intended for internal use in com-

**In this Chapter**

panies when working with product development. In 1999 a more complete version was published, Eco-indicator 99. This version was adapted to European conditions. Thus the geographical dimension of the LCA was taken care of already in the database, and no special study of the local conditions for each pollutant was needed.

The Eco-indicator method is a multi-step process (Figure 7.1). It starts with the calculation of the environmental loads from the product life cycle. In the following two steps the exposure and effect of the exposure, using average European data, are calculated. Then follows the critical issue: what should be considered an environmental problem. In the Eco-indicator approach three damage categories, so-called *endpoints*, are distinguished: Human Health, Ecosystem Quality and Resources.

The three categories are not sufficiently self-explanatory, and a description of what is included in each of the three terms is necessary for building up the methodology.

The *Human Health* category contains the idea that all human beings, present and future, should be free from environmentally transmitted illnesses, disabilities or premature deaths.

The *Ecosystem Quality* category contains the idea that non-human species should not suffer from disruptive changes in their populations and geographical distribution.

The *Resources* category contains the idea that nature's supply of non-living goods, which are essential to human society, should be available also for future generations.

It would also be possible to select other damage categories, such as material welfare, happiness, equality, safety, etc., but in the Eco-indicator methodology they are not included. This is partially because it is too complex to define or model such damage categories, and partially because in general products can have both an intended positive effect as well as a negative (environmental) effect. This may for instance lead to the strange conclusion that pesticides have a strong positive effect on human welfare (e.g. because of increased food production), while at the same time Human Health (because of their toxicity) could be threatened.

Figure 7.2 shows in general the Eco-indicator methodology. The white boxes refer to the procedures; the other boxes refer to the (intermediate) results.

### 7.2.2 Eco-indicator for Human Health

The health of any human individual, being a member of the present or a future generation, may be damaged either by reducing the duration of his or her life by premature death, or by causing a temporary or permanent reduction of body functions (disabilities). The environmental sources for such damages include e.g.:

- Infectious diseases, cardiovascular and respiratory diseases, as well as forced displacement due to the climate change.
- Cancer as a result of ionizing radiation.
- Cancer and eye damages due to ozone layer depletion.
- Respiratory diseases and cancer due to toxic chemicals in air, drinking water and food.

These types of damages represent important threats to Human Health caused by emissions from product systems. The

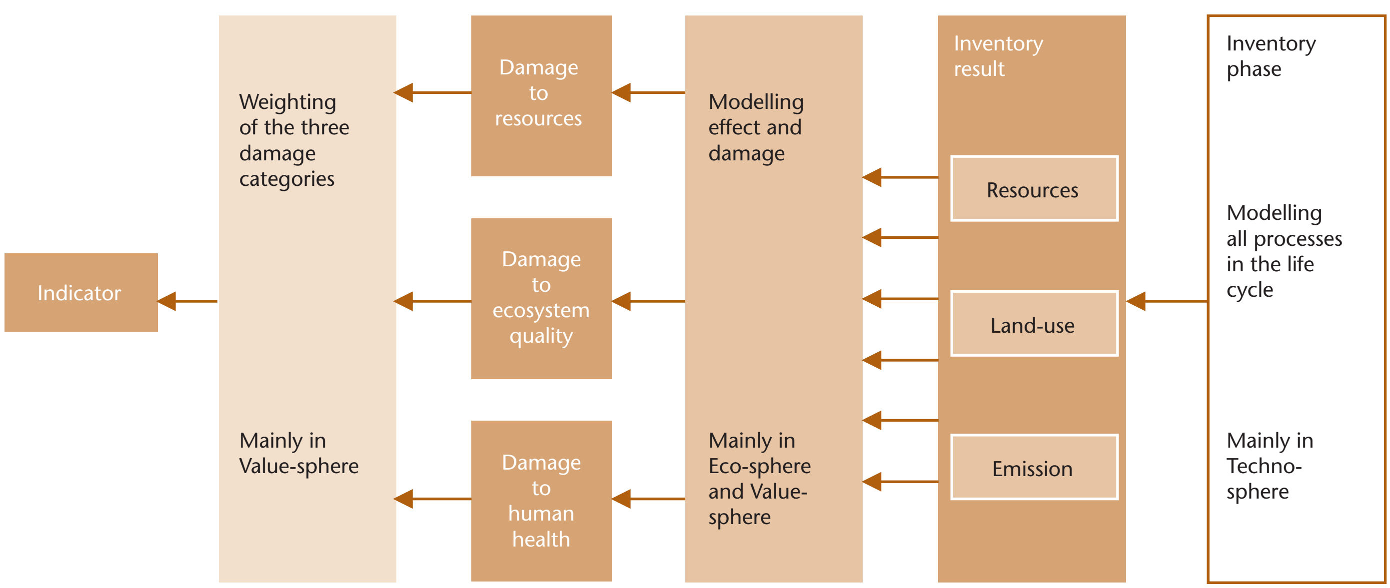



**Figure 7.1** *The eco-indicator concept [Goedkoop, 1995].*

damage category is, however, far from complete. For instance, health damage from emissions of heavy metals such as Cd and Pb, of endocrine disrupters etc. as well as health damages from allergenic substances, noise and odour are not yet modelled in Eco-indicator 99.

### 7.2.3 Eco-indicator for Ecosystem Quality

Ecosystems are very complex, and it is very difficult to determine all damage inflicted upon them. An important difference compared with Human Health is that even if you could, you are not really concerned with the individual organism, plant or animal. The species diversity is used as an indicator for Ecosystem Quality. You can express the ecosystem damage as a percentage of species that are threatened or that disappear from a given area during a certain time.

For *ecotoxicity*, Eco-indicator 99 uses a method recently developed in the Netherlands for the Dutch Environmental Outlook [Van de Meent et al., 1997]. This method determines the Potentially Affected Fraction (PAF) of species in relation to the concentration of toxic substances. The PAFs are determined on the basis of toxicity data for terrestrial and aquatic organisms like microorganisms, plants, worms, algae, amphibians, mollusks, crustaceans and fish.

The PAF expresses the percentage of species that is exposed to a concentration above the No Observed Effect Concentration (NOEC). A higher concentration caused a larger number of species that are affected. The PAF damage function has a typical shape as shown in Figure 7.3. A Logistic PAF-curve expresses the potential affected fraction of species at different concentrations of a substance.

When a chemical is emitted in an area, its concentration in the area will increase temporarily. This change in concentration will cause a change in the PAF value. The damage caused by the emission of this substance depends on the slope of the curve in a suitably chosen working point.

Being based on NOEC, a PAF does not necessarily correspond to an observable damage. Even a high PAF value of 50% or even 90% does not have to result in a really observable effect. PAF should be interpreted as toxic stress and not as a measure to model disappearance or extinction of species.

For *land use*, Eco-indicator 99 also uses the Potentially Disappeared Fraction (PDF) as an indicator. In this case however, you do not consider target species but all species. The damage model is rather complex, and include four different models:

- The local effect of land occupation.
- The local effect of land conversion.
- The regional effect of land occupation.
- The regional effect of land conversion.

The local effect refers to the change in species numbers occurring on the occupied or converted land itself, while the regional effect refers to the changes on the natural areas outside the occupied or converted area. The regional effect was first de-

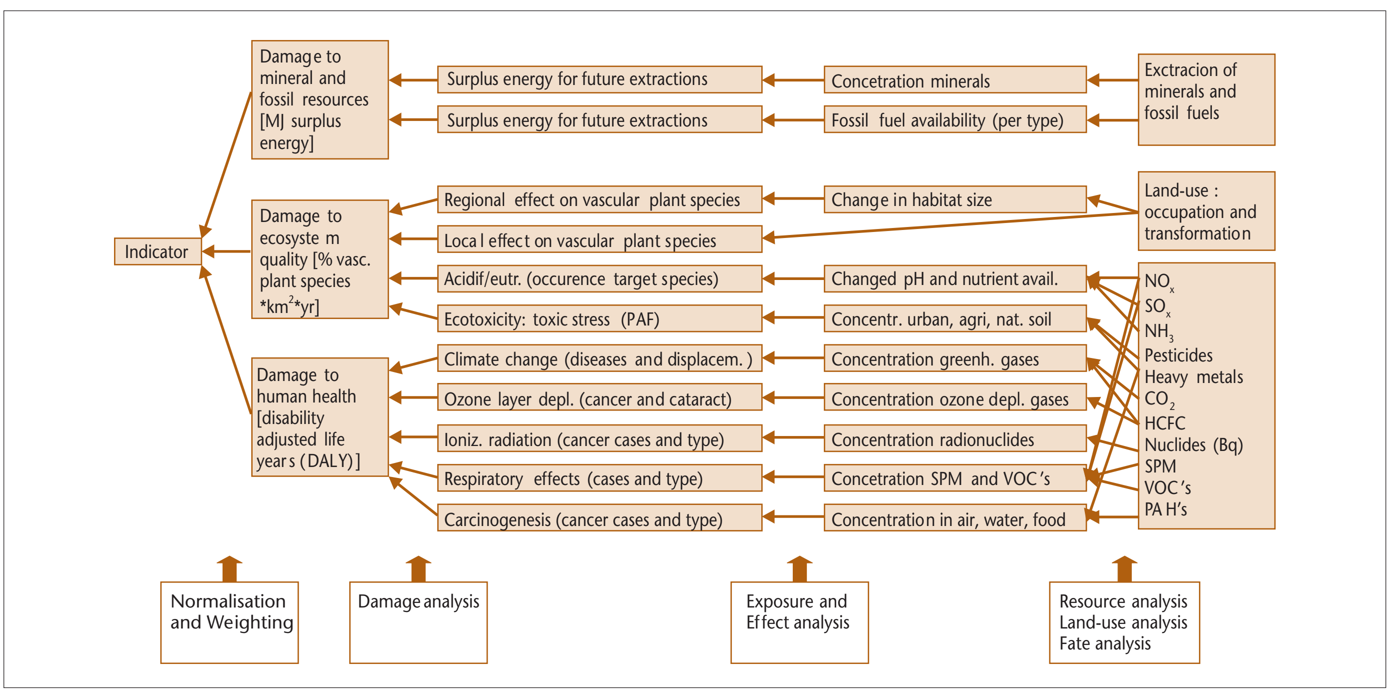



**Figure 7.2** *Eco-indicator methodology [Goedkoop, 1995].*

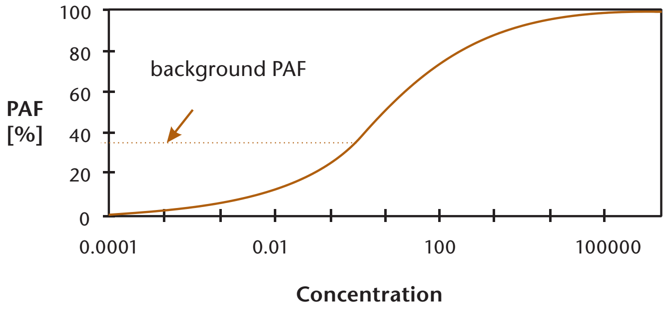



**Figure 7.3** *The PAF-curve, Potentially Affected Fraction of species as a function of the concentration of a single substance (%) [Goedkoop, 1995].*

scribed by [Muller-Wenk, 1998]. The data for the species numbers per type of land-use and some of the concepts used for the local effect are based on [Köllner and Jungbluth, 1999].

The data on the species numbers are based on observations, and not on models. The problem with this type of data is that it is not possible to separate the influence of the type of land use from the influence of emissions. For this reason special care must be taken to avoid double counting of effects which are included in land-use and which could be included also in other damage models.

The Ecosystem Quality damage category is the most problematic of the three categories, as it is not completely homogeneous. As a temporary solution one may combine PAF and PDF.

### 7.2.4 Eco-indicator for Resources

In the case of non-renewable resources (minerals and fossil fuels), it is obvious that there is a limit on the human use of these resources, but it is rather arbitrary to give data on the total quantity per resource existing in the accessible part of the earth crust. The sum of the known and easily exploitable deposits is quite small in comparison with current yearly extractions. If one includes occurrences of very low concentrations or with very difficult access, the resource figures become huge. It is difficult to fix convincing boundaries for including or not-including occurrences between the two extremes, as quantity and quality are directly linked.

To tackle this problem, the Eco-indicator methodology does not consider the quantity of resources as such, but rather the qualitative structure of resources.

Market forces assure that the deposits with the highest concentrations of a given resource are depleted first, leaving future generations to deal with lower concentrations. Thus in theory, the average ore grade available for future generations will be reduced with the extraction of every kilo. This decreasing concentration is the basis for the resource analysis.

The resource analysis is quite comparable to the fate analysis; instead of modelling the increase of the concentration of pollutants, we model the decrease of the concentration of mineral resources.

Chapman and Roberts [1983] developed an assessment procedure for the seriousness of resource depletion, based on the energy needed to extract a mineral in relation to the concentration. As more minerals are extracted, the energy requirements for future mining will increase. The measure of damage used in the Eco-indicator for resource extraction is based on this work. It is the energy needed to extract a kg of a mineral in the future. Much of the data is supplied by [Muller-Wenk, 1998].

### 7.2.5 Calculating the Eco-indicator Value

The Eco-indicator values for a certain impact are expressed as a sum of impacts for each of the three categories. Each of the impact categories are expressed in one unit. Impact on human health is expressed as DALY, Disability Adjusted Life Years, that is the number of years of life lost and the number of years lived disabled. Impact on ecosystem quality is expressed as the loss of species over a certain area during a certain time PDF *x* $m^2$ *x* year (PDF=Potentially Disappeared Fraction). Depletion of resources is expressed as surplus energy needed for future extractions of minerals and fossil fuels. The principle of damage assessment is shown in Figure 7.4, [Goedkoop and Oele, 2001].

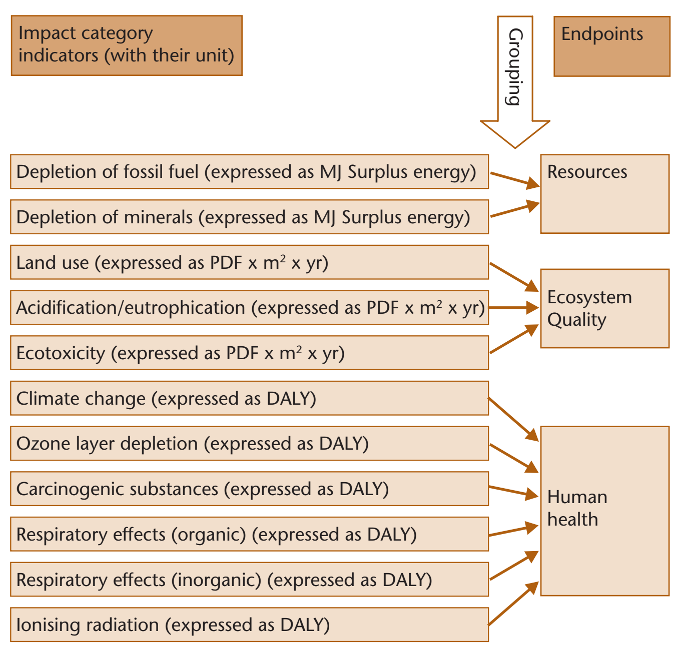



**Figure 7.4** *Principle of damage assessment in Eco-indicator 99.*

In the Eco-indicator tables published by Goedkoop and Spriensma [1999] the seriousness of the impact is judged from three perspectives, the hierarchist, the egalitarian and the individualist perspectives. The egalitarian uses the precautionary principle systematically and a long-term view is applied. This means that nothing is taken for granted and a maximum possible impact is used for the indicator. The individualist uses only proven effects of a certain impact when calculating the Eco-indicator value. Finally the hierarchist uses impacts, which are substantiated by scientific facts, but not necessarily demonstrated in actual cases. The hierarchist values normally end up between the other two (Table 7.1; See also Box 2.5 for further explanations of the three concepts).

When including all three in a report on the life cycle impact assessment of a future product, it will give an idea of the range of possible future impacts as judged by the Eco-indicator 99 method. In this way a final report will contain nine values, three perspectives for each of three damage categories. In addition one needs to be aware that a number of possible environmental effects are not treated in the Eco-indicator 99 method.

## 7.3 Proxy Methods

### 7.3.1 Using Single Dimensions to Asses Environmental Impact

Proxy methods are those where a single dimension is used to reflect the total environmental impact of a product or service.

Very early on, *energy consumption* was used to estimate the total impact of a product. Cramer et al. [1993] used the reduction of energy consumption to assess the improvement of a product over its predecessors. In a life cycle perspective it is important to include energy use in all stages of a product or service, extraction of resources, large e.g. for aluminium, production stage, use phase and waste phase. All other kinds of impact are then assumed to be roughly proportional to energy use.

*Money* can also be used as a proxy parameter for environmental impact. The costs of controlling and reducing impacts are added up using the target values in permits according to environmental authorities. Money is also used as a parameter in the EPS method (see below) then using the willingness-to-pay for avoiding the impacts to estimate the costs.

**Table 7.1 Weighting indices according to Eco-indicator 99.** *Selected illustrative data from Goedkoop and Spriensma [1999], based on distance-to-target principle, and as seen from three different cultural perspectives; hierarchist, egalitarian and individualist. (See also Box 2.5).*

| Substance | Damage category | Hierarchist weights | Egalitarian weights | Individualist weights |
|---|---|---|---|---|
| *Resource use (/kg)* | | | | |
| Coal (29.3 MJ/kg) | Resources | 0.00599 | 0.0687 | 0 |
| Crude oil (41 MJ/kg) | Resources | 0.140 | 0.114 | 0 |
| Natural gas (30.3 MJ/kg) | Resources | 0.108 | 0.0909 | 0 |
| Aluminium ore (Bauxite) | Resources | 0.0119 | 0.0168 | 0.667 |
| Copper ore | Resources | 0.00987 | 0.0140 | 0.553 |
| Iron ore | Resources | 0.000690 | 0.000976 | 0.0387 |
| Zinc ore | Resources | 0.00178 | 0.00253 | 0.10 |
| *Ecosystem quality land use (/$m^2$ year or /$m^2$)* | | | | |
| Industrial area | Occupation (/$m^2$ year) | 0.0655 | 0.0819 | 0.0466 |
| Industrial area | Conversion (/$m^2$) | 1.96 | 2.45 | 1.39 |
| Forest land | Occupation (/$m^2$ year) | 0.00858 | 0.0107 | 0.00610 |
| Farm land | Occupation (/m2 year) | 0.0897 | 0.112 | 0.0637 |
| Farm land | Conversion (/$m^2$) | 2.68 | 3.35 | 1.91 |
| *Emission to air (/kg)* | | | | |
| CO | Human health, respiratory | 0 | 0.00579 | 0 |
| $CO_2$ | Human health, climate | 0.0297 | 0.0222 | 0.0497 |
| $NH_3$ | Human health, respiratory | 0.0902 | 0.673 | 0.938 |
| $NH_3$ | Ecosystem quality | 1.21 | 1.52 | 0.863 |
| $NH_3$ | Sum, $NH_3$ to air | 2.112 | 2.193 | 1.801 |

In the MIPS method *material flows* caused by the production, use and wasting of a product or service are used as a proxy parameter. The MIPS method has been carefully evaluated and it is argued that the material flows are roughly proportional to toxic flows and other impacts, which should make MIPS a valid proxy method.

*Surface area use* is a proxy method in the ecological footprint method. In this method a calculation is made of the area in nature used for the services a product needs. This method is today the most widely used proxy method for estimating the total impact of a person, household, a city or a country.

### 7.3.2 The MIPS Methodology

*Material Input Per Service unit*, MIPS, is a concept developed by the Wuppertal Institute for Climate, Environment and Energy, Germany. It was developed to answer the question of how flows of materials (abiotic materials, water and air) in nature are mobilized to provide a certain product or service in society. From a practitioner's point of view the algorithm used in a MIPS analysis is entirely different from the methodologies presented so far. In practice the analysis is performed in the following stages:

1. Firstly, the life cycle of the product to be investigated is defined, and the relevant data describing of material and energy consumption during successive life stages is gathered.
2. The data for material and energy consumption expressed in appropriate units are multiplied by corresponding coefficients derived from a MI, *material intensity*, database in three categories: water, air and abiotic resources.
3. The results are summed up to obtain overall environmental loads for each life stage or the whole life cycle. The life stages which cause the highest environmental burden can be identified with the most exploited part of the environment (water, air or abiotic resources) indicated. For a comparative LCA analysis, the most preferable option can be chosen.

**Table 7.2** *Examples of MIPS indices, or material itensities, MI (http://www.wupperinst.org/Projekte/mipsonline).*

| Materials/products/modules | Abiotic materials (t/t) | Water (t/t) | Air (t/t) |
|---|---|---|---|
| Primary steel | 7.0 | 44.6 | 1.3 |
| Secondary steel | 3.5 | 57.5 | 0.6 |
| Copper | 500 | 1378.6 | 2.0 |
| Aluminium | 85.0 | 1379.0 | 10.0 |
| Plastics | 8.0 | 117.7 | 0.7 |
| Glass | 3.0 | 11.7 | 0.7 |
| Fuel | 2.5 | 11.7 | 3.3 |
| Operating liquids | 1.2 | 4.3 | 3.1 |
| Non-electric energy | 1.4 | 9.5 | 3.1 |
| Oil | 1.2 | 4.3 | 3.1 |
| Tyres | 2.9 | 19.4 | 0.7 |
| Road infrastructure maintenance | 150 | 211.7 | 5.1 |
| Peripheral infrastructure | 21.2 | 319.6 | 2.4 |
| Car maintenance | 12.52 | 92.5 | 1.6 |
| | **kg/unit** | **kg/unit** | **kg/unit** |
| Autocatalysts | 2000.0 | | |
| Car washing | 27.5 | 583.7 | 3.5 |
| | **kg/kWh** | **kg/kWh** | **kg/kWh** |
| Process (electric) energy | 4.7 | 93.1 | 0.6 |
| | **kg/tkm** | **kg/tkm** | **kg/tkm** |
| Transport | 0.25 | 1.8 | 0.1 |

### 7.3.3 Calculation of MIPS

The MIPS is a material intensity concept, a measure of the quantity of materials consumed to provide a certain service. MI indices show how much water, air and abiotic resources are needed on average to produce a unit amount of a certain material. For example to obtain 1t of primary steel 7t of abiotic resources, 44.6t of water and 1.3t of air are used. Thus much more resources – a total of 53 tonnes – are used to produce a smaller amount of useful product – 1 tonne of steel. As a consequence, these material flows result in various kinds of emissions, exhaustion of resources etc, which can lead to different environmental damage and effects on health. The material that is moved or extracted but not included in the final product is called "the ecological rucksack".

The MIPS database, which can be found on the Internet, consists of calculated indices for basic chemicals, building materials, etc, which usually are inputs in industrial systems. Unfortunately, the data do not cover all of possible inputs but just the most common of them, which is the major weakness of the method. Still several hundreds MI indices are available. (see Internet Resources). Examples of MI indices are given in Table 7.2.

### 7.3.4 Strength and Weaknesses of MIPS

The MIPS method is useful to estimate the material flows and ecological rucksacks associated with many services. The MIPS method is clear and easy to implement, allows quick assessment and gives the result as a single value, a kind of environmental index. A MIPS analysis is possible to carry out with a simple calculator, which is also an advantage. This feature makes MIPS analysis suitable for screening.

There are also several drawbacks, not surprising considering that it is a simple method. First it does not cover all important impact categories. Even if it shares this weakness with practically every LCIA method, it is more evident here. Most often mentioned is that some ecological rucksacks are trivial and does not represent serious environmental impacts. Thus moving gravel, sand and stone, often for building purposes, are not necessarily environmentally serious, but may result in a large MIPS value. A second criticism is that toxic effects or materials are not evaluated separately, that is, MIPS is only a quantitative, not qualitative, method. One may however do this and derive what is called TIPS (Toxicity Input Per Service unit) or refer to the observation that as an average the material flows in practice is proportional to toxic material flows. Still, if toxicity should be considered properly for a specific product or service, a more advanced LCIA is required, either an eco-indicator analysis or a full LCA.

The results obtained with the aid of MI indices are not good enough to be used externally as marketing claims. However the MIPS analysis shares this limitation with most present LCIA methods.

### 7.3.5 The Ecological Footprint Method

The concept of the *ecological footprint* was introduced by Wackernagel and Rees [Wackernagel and Rees, 1996] in the late 1980s and early 1990s. The idea was to reduce all ecological impacts of a product or service to the surface area in nature that was necessary to support its use /production. They argued that any production or other service in society is dependent on one or several *ecological services*, and that each of these required a small area in nature. The sum of these areas constituted the footprint of that production or service. Five main categories of ecological services were considered:

**Box 7.1**
**How to Calculate the Ecological Footprint**

It is easiest is to calculate a footprint for a country since the statistics needed are usually available on a national basis. The energy used, food products, built areas, paper consumed etc., all in the national statistics, may be converted to per capita by dividing by the number of inhabitants.

Detailed statistics are used for the calculations. For example what is the footprint of a daily newspaper? One tonne of paper requires 1.8 $m^3$ of wood. This is compared to the productivity of 2.3 $m^3$/ha/yr (an approximate value for Baltic region forests), yielding 0.78 ha. Since a common daily paper itself weighs some 100 kg a year, it has a footprint of 0.078 ha. This is an underestimation since many components, for example energy and transport, were not included. On the other hand the use of recycled paper decreases the figure, up to three times (up to 2/3 of the fibres may come from recycling).

For energy calculations three methods have been used. For 100 Gigajoules biomass, some 1.25 ha land will be needed. If wood is converted into ethanol we get the same figure, 1.25 ha. If we estimate the area needed for $CO_2$ absorption corresponding to the same amount, it is 1.0 ha. The area for producing 100 Gigajoules is much smaller for windmills and hydropower stations.

*Source: M. Wackernagel and W. Rees (1996), Our Ecolgical Footprint. Reducing human impact on the Earth.*

1. *Agricultural land*, needed for food production, grain or meat.
2. *Forest land*, needed for production of fibres, timber, paper etc.
3. *Energy land*, needed for production of energy, calculated as biomass or other forms of energy, such as ethanol from grain or methanol from wood
4. *Waste sinks*, land to absorb waste, such as carbon dioxide or nutrients.
5. *Built land*, used for infrastructure, buildings, roads, etc.

The calculation of a footprint is possible by quite simple methods (http;//www.footprintnetwork.org). The results and methods are very useful for pedagogical purposes. It is easy to understand, even for small children, and it demonstrates clearly that no service or products can appear unless some ecological services are used. As an exercise it is possible to calculate the ecological footprint of your daily newspaper (Box 7.1). When a more sophisticated LCA analysis of the newspaper is not possible, the calculation of a footprint may suffice for the purpose at hand, and of course it is much quicker.

The method has several weaknesses. The footprints do not include impact on humans; the capacity of nature to absorb many of the emissions of a modern production are not reflected; the damages to ecosystems is not properly included.

Nor is the exact value of the footprint without weak points. The importance of marine areas for ecological services is not normally taken into account, nor are different types of natural areas, even though these have different capacities to provide the services in question. Thus the absolute values of footprints may be questioned. Still if the same factors are used in the calculations, comparisons of products or services should be valid.

## 7.4 Ready-made Methods for Design of Industrial Products

### 7.4.1 EPS, Environmental Priority Strategies

EPS was created to provide designers with a simple means to compare products or product designs using a single score. EPS stands for Environmental Priority Strategies in Product Design. It was originally devised by Ryding and Steen [1991] for the Volvo Car Company in Sweden. It has later been further developed [Steen and Ryding, 1992 and Steen, 1999].

EPS addresses five categories of impact:

1. Human health,
2. Biological diversity,
3. Ecosystem production capacity
4. Abiotic resources and
5. Cultural and recreational values

Each of these has several sub-categories, called *unit effects*. An example of a unit effect is the decreased production of 1 kg of crop seed or wood or fish caused by an emission (a unit effect of category 3 Ecosystem production capacity). The effects are expressed in the unit of economic value as measured by the willingness-to-pay to avoid the effect. The price of avoiding the unit effect thus serves the purpose of being a weighting factor in the EPS method. The method lists known impacts and for each of them an uncertainty factor. (This uncertainty factor addresses the same problem that the Eco-indicator method handles by giving three values.)

The EPS method starts as always by assessing the impact or emissions from each life stage of a product. One then translates each emission into a price based on its effect on each unit effect. The sizes of the impacts are then multiplied by the respective index (price) and summed up.

### 7.4.2 Calculating the EPS Index for Emission of one kg of Mercury

By way of illustration we will calculate the EPS index for the emission of 1 kg of mercury [data from Steen, 1999a and 1999b]. Emission of mercury is common e.g. in combustion of coal in a coal-fired power plant, or in incineration of household solid waste. Reduction of mercury emissions is possible with proper flue gas cleaning. The EPS index can be used in product development but in this case also for a cost-benefit analysis regarding the installation of flue gas cleaning equipment.

For the Human Health category it is assumed that 400,000 persons are affected per year. 1 kg of Hg is $1.2 \times 10^{-8}$ of the global annual emissions. The value of the unit effect is set to 10,000 Euro/person/year. The indicator value is thus the product of these three or 48.08 Euro.

For the Ecosystem Production category only effects on fish are considered. It is assumed that 18,500,000 kg of fish is affected. As before, the contribution to global annual emissions is $1.2 \times 10^{-8}$. The value for avoiding the effect is for one kg of fish set at 1 Euro per kg. The product 0.22 Euro is the indicator value for the category Ecosystem Production.

For the Biodiversity category the EPS method uses the NEX index, the Normalised Extinction of Species reported for the 1990s. It is 0.01 for mercury. As before, the contribution to global annual emissions is $1.2 \times 10^{-8}$. The value of avoidance is $110 \times 10^{9}$ per NEX. The product for this category is 13.2 Euro.

For the Cultural Values category there is no defined impact, and the Abiotic Resources category is not used for emissions. The sum of the index for the impact of one kg of emitted mercury is thus 61.5 Euro.

### 7.4.3 EDIP Environmental Development of Industrial Products

EDIP was created in Denmark with the purpose of making possible the comparison of products or product designs in Danish industry using a single score [Wenzel et al., 1997]. The impact categories used in EDIP include global warming, ozone depletion, acidification, eutrophication, waste, persistent toxicity, ecotoxicity, human toxicity, and work environment. The toxicity values are based on physicochemical data such as bioaccumulation potential (expressed as water-octanol distribution, $k_{ow}$ coefficient), and concentration in air inhaled.

Each impact is then divided by the total impact in the relevant geographical area, such as a country. In this way an estimate of the relative contribution to the total impact is received. The fraction of each category is then multiplied with a weighting factor to reflect its severity. The products are then added up to a total index. Weighting is done using Danish statistics.

The result is thus an index, which is a dimensionless number.

## Study Questions

1. Describe how you work with the Eco-indicator method.
2. Describe the MIPS methodology, and its strengths and weaknesses.
3. Describe the ecological footprint methods, and its strengths and weaknesses.
4. Describe the EPS method.
5. Discuss differences between Eco-indicator, MIPS and ecological footprint.
6. How do you understand impact categories and damage categories?
7. What is an ecological service?
8. Clarify the notion of Hierarchist, Egalitarian and Individualist understanding of seriousness of impact.

## Abbreviations

| | |
|---|---|
| EDIP | Environmental Development of Industrial Products. |
| EPS | Environmental Priority Strategies in product design. |
| DALY | Disability Adjusted Life Years. |
| LCA | Life Cycle Assessment. |
| LCIA | Life Cycle Impact Assessment. |
| MIPS | Material Input per Service Unit. |
| NEX | Normalised Extinction of Species. |
| NOEC | No Observed Effect Concentration. |
| PAF | Potentially Affected Fraction. |
| PDF | Potentially Disappeared Fraction. |

## Internet Resources

PRé Consultants: Eco-indicator 95
impact assessment & ecodesign method
http://www.pre.nl/eco-indicator95/

PRé Consultants: Eco-indicator 99
impact assessment & ecodesign method
http://www.pre.nl/eco-indicator99/

The Wuppertal Institute
http://www.wuppertalinst.org

The Wuppertal Institute – The MIPS database (MI indices)
http://www.wupperinst.org/Projekte/mipsonline/

The Global Footprint Network
http://www.footprintnetwork.org/

A simple way to calculate your own footprint
http://www.bestfootforward.com/footprintlife.htm

Centre for Environmental Assessment
of Product and Material Systems, CPM,
Chalmers University of Technology – tools for LCIA
http://www.cpm.chalmers.se/freetools.htm

Software Tools Collection at Tufts University,
MA, USA (Gloria, 2005).
http://www.life-cycle.org/

Information at ESU-services
(energy-materials-environment) of Rolf Frischknecht.
http://www.esu-services.ch

# 8 LCA Information Management

## 8.1 Setting up an Information Management System

### 8.1.1 The System Components

This chapter describes how to document and communicate complete data models of LCA analyses of products and systems. How to perform the actual modelling of an LCA analysis will not be described in detail. The approach as described below is a mix of academic and industrial approaches. The academic approach is based on a model design developed at CPM. This approach is called PHASETS (PHASEs in the modelling of a Technical System.) [Carlson and Pålsson, 1999] and can be used to structure the work when accomplishing a model of a technical system.

The modelling of a system may be considered to consist of six distinct phases, through which data and information passes. Information is communicated from simple to more aggregated concepts:

1. *Setting up the measurement system*. The measurement system for parameters considered environmentally relevant are established and maintained.
2. *Sampling*. A sample is taken from the measurement system, following the routines defined by the measurement system in phase 1.
3. *Forming a frequency function* from individual sample sets; samples from phase 2 are statistically interpreted and analysed.
4. *System synthesis;* modelling the technical system. A model of a technical system is synthesised, choices are made regarding functional unit, system content and system boundaries; the frequency function from phase 3 is used to quantify the inflows and outflows of the model.
5. *Aggregation of models of technical systems*. Models of technical systems are used to form an aggregate model, such as an average or a process or product flow chart.
6. *Contextual transfer*. Between any two phases information is communicated, and the communication is generally

**In this Chapter**

1. Setting up an Information Management System.
   - The System Components.
   - Product Data Management, PDM.
2. Data Analysis and Acquisition.
   - Data Analysis of Quality and Completeness.
   - Life Cycle Inventory (LCI)-data Analysis.
   - Modelling the System.
   - Acquisition of data.
   - Data Quality.
   - Reliability, Accessibility, and Relevance.
   - Data Sources.
3. Data Structuring and Documenting.
   - LCA Data Models.
   - The Production Unit.
   - Data Documenting.
   - Assuring Data Quality.
4. Data Transfer.
   - Documentation of Data.
   - Working with Secondary Sources.
   - Actions to Avoid Miscommunication.
   - Aggregated LCI Analysis.
   - Lacking Information.
   - Unambiguous Data Transfer.
5. Using Information Technology.
   - Product Data Management, PDM.
   - Web Based Product Data Management (PDM 2000).
   - Web Based PDM Systems.

done between different contextual environments (in order for the data and information to be correctly interpreted, the communicating parties should consider differences in contextual environment).

### 8.1.2 Product Data Management, PDM

In industry there are many Product Data Management (PDM) systems designed for a general-purpose database to support logistics management of complex systems [Jones, 1995]. Questions to be answered regarding the information and communication structure are:

- *What* information will be required.
- *How* to collect, classify, document and communicate this information.

PDM 2000 is an information management approach developed to support the material logistic processes in industry, defence, transport, etc. The information management concept of Bourgonje et al. [1995] has been adopted to develop this approach (Figure 8.1). In line with this approach the material logistics field of interest is divided into four specific areas:

- Defining and designing information.
- Production and/or acquisition of information.
- Operations and maintenance of information.
- Management of information.

To manage the information processes, that is, to get and maintain a grip on it, the following four specific information management objectives are defined:

- Acquisition. Generating and gathering information.
- Structuring information.
- Document information.
- Transfer information.

*Structuring information* is a process to structure the data sets (documents) and the data flows.

*Document information* is the process in which outline/form information is represented. In line with Bourgonje (1995) methods and techniques are discussed for developing or selecting information outlines/forms so as to provide easily-accessible information for all involved actors in a cost-effective way.

*Transfer information* is primarily focused on methods of information distribution. Specific attention is given to Internet web technology in combination with the database interface technologies.

## 8.2 Data Analysis and Acquisition

### 8.2.1 Data Analysis of Quality and Completeness

A number of general rules apply for the evaluation of data quality:

- The mass balance must be checked for material processing systems.
- The results must be compared with at least one other more or less comparable processes, and any large variations must be explained.
- Where data are clearly missing, estimates must be made.

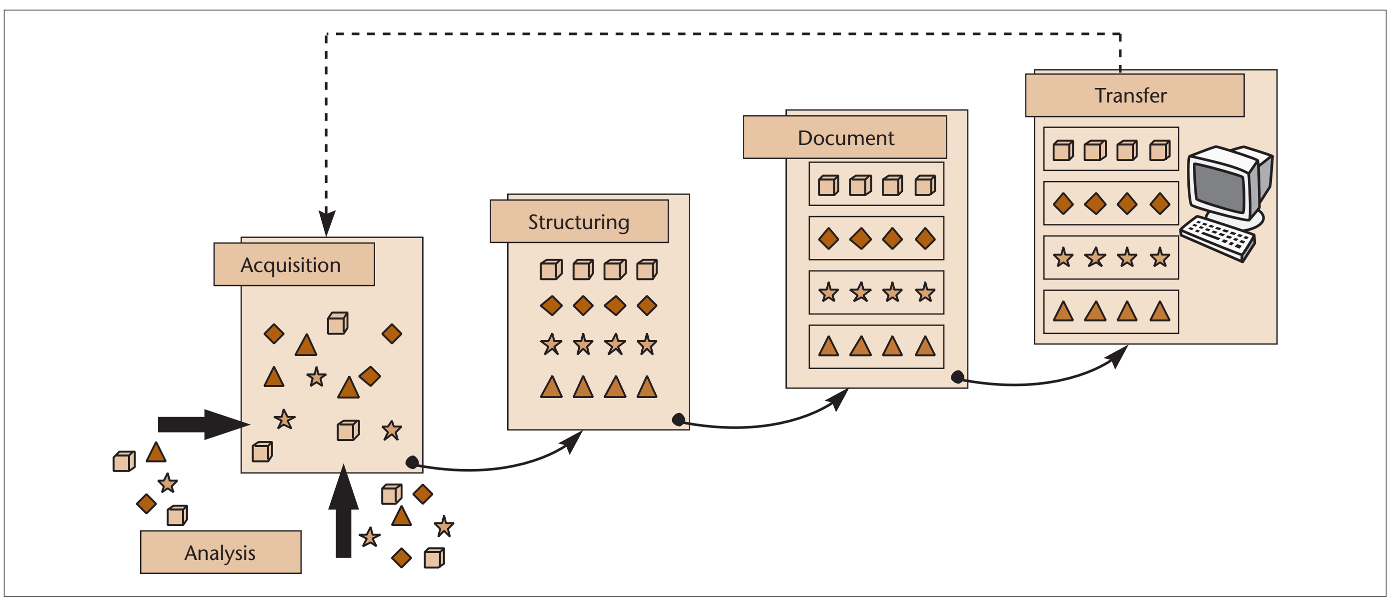



**Figure 8.1 Product data management.** *Information management includes four stages, acquisition, structuring, documentation and transfer of data [Bourgonje et al., 1995]. Each of these will be described in some detail in the chapter.*

The data also needs to be structured. The following data at least must be recorded for each product and process.

1. Definition of the material or process.
2. Sources used.
3. Type of technology, region and period, where known.
4. Graphic representation of the process tree, with the system boundaries clearly shown.
5. Complete impact table, with impacts divided by:
   - Use of raw materials (in connection with mass balance checks).
   - Emissions to the air.
   - Emissions to water and soil.
   - Final waste (in connection with mass balance checks).
6. In every case the results of the quality tests described above must be given:
   - Mass balance.
   - Origin of the data.
   - Comparison with other data.
7. Brief discussion of the consequences of these variations for the result.

Despite all the precautionary measures taken there is a fairly large degree of *uncertainty in the impact tables*. These uncertainties are very difficult to quantify. Nothing is in fact known about the distribution, but it is probably not stochastic which makes it difficult to use an uncertainty analysis. It does not seem impossible for the Eco-indicator to be erroneous by a factor of 2 in some cases because of uncertainties in the impact table. This estimate cannot, however, be backed up.

### 8.2.2 Life Cycle Inventory (LCI)-data Analysis

Life Cycle Inventory (LCI)-data is data that describes environmentally relevant in- and outflows of a defined model of a technical system (Figure 8.2). Matter and energy are used in the technical system in order to fulfil a function, expressed by a functional unit or a functional flow.

The function of a technical system may for example be the production of a certain product and the functional unit may have been chosen as for example 1 kg of that material. Examples of inflows considered relevant are natural resources, raw materials, different kinds of energy, auxiliary material etc. Examples of outflows are products and by-products, emissions to air, water and soil, waste etc.

Examples of models of technical systems that are studied in LCA are individual process steps or production lines within a site, entire plants, transports and transportation routes, and complex composite systems such as production systems for specific products from cradle-to-grave.

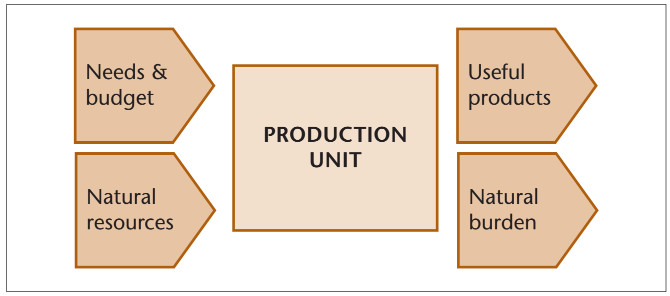



**Figure 8.2 Life Cycle Inventory (LCI) elements.** *The elements of a technical system included in a model, is crudely described here. The Life Cycle Inventory consists of the quantitative data of the material flows in this system.*

A model of a technical system may have an inner structure, i.e. be composed of models of technical subsystems (Figure 8.3). For example, when performing an LCA, a flow model of the studied production system is accomplished by linking models of smaller technical systems together in a flow chart. Thus, the complete LCI may be seen as LCI-data. Also, other types of flow models may be constructed and used in LCA. For example, a model of a production line within a site (system to be analysed) may be composed of models of the included process steps.

### 8.2.3 Modelling the System

The acquisition of LCI-data involves the modelling of a (technical) system and quantification of in- and outflows of the system. Models of systems that are used in LCA are defined to describe the real system represented by the model, as closely as possible. Every model is uniquely designed for a specific purpose and intended application. In some cases the model may have wide applicability. In other cases the model can only be used for the specific application for which it was designed. For the applicability of the model to be correctly assessed, the model and the choices made in the design of the model need to be carefully described.

When modelling a technical system, many different subjective choices are made, all of which have a great influence on the result. Depending on the purpose of the model, the system content and system boundaries are chosen to represent the technical system desired as correctly as possible. If the system performs more than one function (e.g. a plant that produces more than one product) it is necessary to allocate the environmental load between the functions. Criteria for determining which flows are considered environmentally relevant are also established in the choice of system boundaries.

Examples of choices made in the modelling, i.e. in the data acquisition, is the choice of production unit, what to include within the LCA system model and what can be included within the product LCA. In the product LCA the in- and outflows are considered environmentally relevant. This gives quantified eco-indicator values.

### 8.2.4 Acquisition of data

In order to obtain quantitative data for the model, different types of sources are used. These include statistically interpreted measured data, theoretical models, estimations etc.

*Measured data* may have been acquired by several different methods, all of which results in data with different precision. The measurements have been performed using a specific measurement system, with an inherent precision and range. In some cases the measurement system that measures a specific quantity does not correspond to the system that is modelled. This is often the case when e.g. modelling a production line for a specific product within an industrial site that produces several products, for instance, if the model describes a production line within a plant, but the measured quantity describes the entire site. Then a model mapping or an allocation needs to be performed to allocate an appropriate share of the measured quantity to the system studied.

Here we need a word of caution. A description of a system intended for an expert in the field, is generally not sufficient for a layman with no prior experience. It is impossible for an LCA practitioner to maintain a thorough knowledge of every product or system that is included in an LCA analysis.

In general, aspects of modelling "smaller" technical systems such as individual process steps or plants (i.e. LCI-data acquisition) have been overlooked in many LCA analyses. The modelling performed when acquiring LCI-data is not recognised, and is often not done consciously. Guidelines for such modelling are rarely available in LCA literature and manuals. However, issues regarding e.g. choice of system boundaries and inclusions and exclusions of system components are equally important regardless of the size or extension of the technical system; whether describing individual products or plants, as when describing complex composite systems such as complete production systems. The modelling when acquiring LCI-data should therefore be equally carefully documented as the modelling done when performing an LCA.

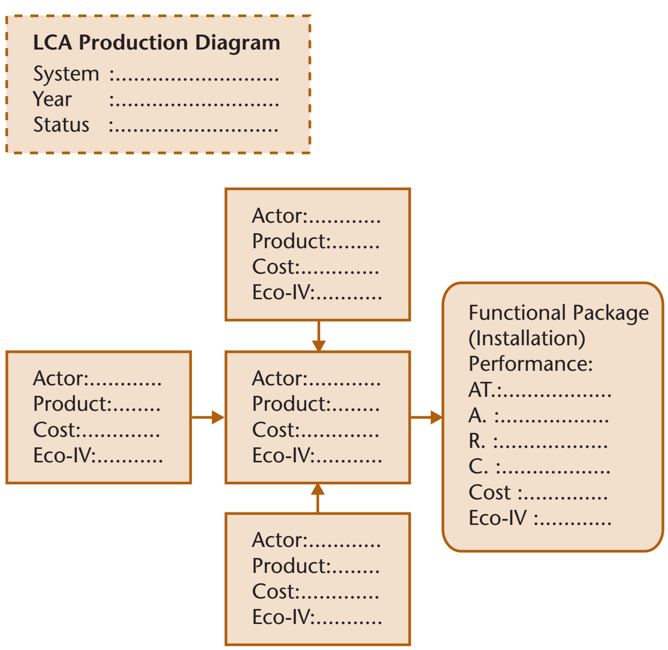



**Figure 8.3 An LCA Production Diagram.** *Most real life technical systems studied in LCA consists of several subsystems. In this diagram four such subsystems are shown. For each of these a Life Cycle Inventory, LCI, needs to be established. Eco-IV is the Eco-indicator Value.*

### 8.2.5 Data Quality

In most LCA's, data description requires many different production units and production diagrams (processes). Depending on the purpose of the study, varying requirements are put on data quality and what type of data can be used in the LCA. Assessment of data quality concerns both qualitative and quantitative aspects such as to what extent the data describes the studied technology, the precision of the data etc., and is thus a complex task, where a multitude of aspects must be considered. The quality of a specific LCI-data set is therefore very much dependent on the context in which it is used. A data-set representing a technical system that may be relevant in one application may be irrelevant or even wrong in a different application, even though certain aspects of the system would apply equally well in both applications. For instance, both systems may deliver the same product but be different in all other respects.

Therefore, the quality of any given LCI-data set in a specific application may only be determined through a thorough knowledge of the system and of the data. Sufficient documentation of the data is fundamental to avoid misuse and misinterpretation of the data. The possibility of assessing the quality can thus be considered a measure of the quality of the data, i.e. the quality of the documentation of the data is in itself a quality aspect. A transparent documentation of the data implies a good basis to judge both the qualitative and quantitative aspects of data quality. This is the only feasible approach to consider and ensure that data quality requirements are met.

The different aspects that should be considered in data quality assessment can be categorised into the three aspects of reliability, accessibility and relevance (Figure 8.4), [Carlson and Pålsson, 1999].

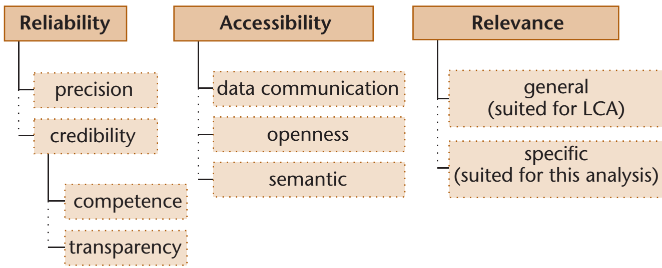



**Figure 8.4 Data quality.** *Good quality data should be reliable, accessible and relevant. The content of these concepts are described.*

### 8.2.6 Reliability, Accessibility, and Relevance

To be able to draw conclusions from the result when using the data, the data should be *reliable*. The reliability of data depends on the precision of data and the credibility of the origin of the data. The precision of data concerns the numerical accuracy and the uncertainty of data. This quality aspect, though important, is not sufficient if all other aspects of data quality are unknown.

The credibility of the origin of the data concerns how credible the data may be considered. For example, any statement regarding precision is useless, unless the data origin may be considered credible. Credibility may be achieved through transparency and competence. A data set may be considered more credible if the data may be transparently reviewed. Also, credibility may only be reached if the data has been acquired by someone with competence regarding the technology and the system that is described by the data. For instance, a data set describing a specific plant would generally be considered more credible if the data is acquired by someone working within the plant who is very familiar with the process, than if the data is acquired by an LCA-practitioner, who is not situated at the plant.

*Accessibility* of data has generally not been considered as a quality aspect, but more as a general problem in LCA. However, if the data is not accessible for the data users, the data reviewers etc., no other quality aspects can be considered. The accessibility of data concerns data communication, openness (after data acquisition) and semantics.

Data communication is an important aspect of accessibility. In order for data to be useful, it needs to be efficiently communicated between the data suppliers and the data users. This may be done in many different forms such as via mail, questionnaires, specific formats etc. Data communication may however only be done depending on the openness after data acquisition. If aspects regarding openness, e.g. secrecy, are not solved or handled adequately, the accessibility of data will be obstructed.

The semantic aspect of data is also a vital component of the accessibility of data. Data are generally acquired within a specific context, for instance within a site. Terminology and other aspects regarding e.g. the technology are implicit and do not need explanation as long as the data is communicated within this specific context. However, if the data is to be communicated to someone who operates in a different context, the terminology and other implicit aspects must be explicitly explained, for the data to be understood and accessible.

Regardless of all other aspects of data quality, if the data is not *relevant* for the context in which it will be used it is not useful. For any specific data set there are two aspects of relevance. The general issue, requires that the data should be suited for LCA. The specific issue, regards whether or not the data is relevant for the application in which it is used.

### 8.2.7 Data Sources

Generally the production units of the producing companies are the major source of data used in LCI. However, at this point LCI-data acquisition within industrial plants often involves isolated activities that take place only when data is required by e.g. a customer. Methodology, resources and routines for LCI-data acquisition is generally lacking and seldom integrated with other data management routines within e.g. an environmental management systems, EMS.

The general approach of the LCA practitioner when acquiring data from producing companies is via *personal communication* or via specifically developed questionnaires.

Another approach to acquiring data from producing companies is to use the *environmental reports* from the companies. However, in general all information required for LCA is not reported in environmental reports. Thus, the information generally needs to be supplemented and the data may also need to be remodelled.

Data may also be acquired from different general sources not specifically developed for LCA, such as: general *technical literature*, process descriptions, theoretical (production) models, logistics support analysis, etc.. Such sources generally require remodelling for the data to be suited for LCA, which in turn requires expertise in the field.

Data found in *LCA reports*, from previous LCA analysis, describes complete models. However, data found in LCA reports are often insufficiently documented. Vital information to assess the models is often missing, for example, descriptions of system boundaries for included subsystems in LCAs are often not given. The information found in LCA reports may also be difficult to interpret due to varying formats for documentation.

The following data quality requirements, according to ISO 14 041:1998(E), should be considered when performing an LCA:

- Time-related coverage.
- Geographical coverage.
- Technology coverage.

Also, further descriptors to define the nature of the data should be given, and the following parameters should be considered at an appropriate level of detail:

- Precision.
- Completeness.
- Representativeness.
- Consistency.
- Reproducibility.

The above requirements may all be grouped into the quality aspects relevance, reliability and accessibility described above:

- *Relevance:* time-related coverage, geographical coverage, technology coverage, completeness representativeness.
- *Reliability:* precision, consistency.
- *Accessibility:* reproducibility, consistency.

## 8.3 Data Structuring and Documenting

### 8.3.1 LCA Data Models

In general a data set displays types of objects and data and their internal relations [Davis and Olson, 1985]. For LCA analysis of systems a conceptual LCA data set has been constructed, based on an LCM approach [Stavenuiter, 2002]. The

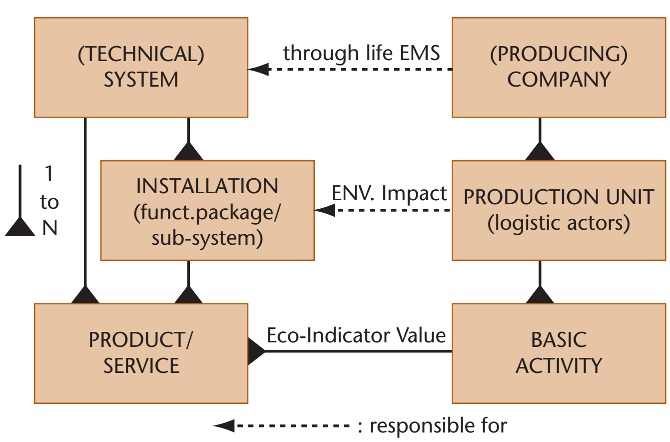



**Figure 8.5 Data responsibility.** *Responsibility for data acquisition is divided between actors in a system. The system is here described according to the Life Cycle Management (LCM) approach.*

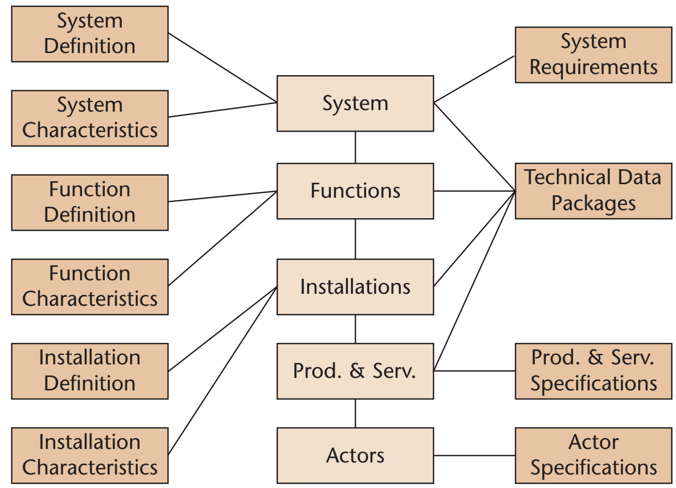



**Figure 8.6 Information records in a technical system.** *The data describing a technical system is distributed between the components shown to the left and right. In the centre is the system itself.*

basic idea behind the LCA data set is to achieve a data model that represents the real system. Also the relationship between the system elements and actors is important to allocate the data responsibility to actors (Figure 8.5).

Allocation of the level of system and data responsibility is essential for continuing the LCA analysis in a structured and controlled manner. The objective of this phase/activity is to achieve an unambiguous understanding of 'who is responsible for what'. The aim is to achieve a shared vision based on the current situation in relation to the basic knowledge gained from the previous analysis.

The conceptual LCA data set should give conceptual insight into the data records and their primary relations. The data set structure will be used as the backbone of all data collected in a later stage. An inventory is made of the system, functions, installations (production lines, machinery, computers, etc.), products & services and actors. The data set kernel is built up of these entities. Figure 8.6 represents the kernel surrounded by the information records.

To illustrate the content of the data sets an example of attributes per entity is given in Table 8.1.

In general the set up depends on the selected LCA analysis method or technique, i.e. the SPLINE format was developed to handle structure and store all relevant information regarding LCA data and was originally implemented as a relational database structure [Carlson et al., 1995].

### 8.3.2 The Production Unit

The central concepts for LCI-data sets and flow charts in SPINE are "production unit" (activity) and "flow" oriented

(Figure 8.2). A production unit corresponds to a part of the LCI-data set related to a model of a (technical) system. A *production unit* consists of the concepts *Object-Of-Study*, *Inventory*, *Flow* and *Q-Meta-Data*. Each of these concepts is defined as follows:

1. *Object-Of-Study:*
   - The description of the technical system.
2. *Inventory:*
   - Description of choices made in the data acquisition and the objective for the choices (e.g. choice of functional unit and system boundaries etc.).
   - Recommendations for the use of data.
   - General and administrative information.
3. *Flow:*
   - Inflows and outflows to the system.
4. *Q-Meta-Data:*
   - Description of the methods used to acquire the numerical data for inflows and outflows.

In addition to this, there are a number of concepts that deal with information used in the description of the data.

5. *Address register. Juridical Person:*
   Handles all addresses that are used in the documentation such as contact persons and addresses to industrial sites. Addresses are specified by name, mailing address, phone number, facsimile number and e-mail addresses to e.g. plants and contact persons.
6. *Nomenclatures:*
   Nomenclatures used for: *Description of the technical system*:
   - Process Type: types of technical systems, names of different sectors.

   Nomenclatures used for: *Inflows and Outflows*:
   - Substance: names of substances.
   - Environment: names of environmental types from which a flow originates when entering or ends up after leaving the technical system.
   - Geography: names of geographical locations from which a flow originates when entering or ends up after leaving the technical system (this is used in the flow table).
   - Unit: units of flows.

   Nomenclatures used for: *Description of the methods used to acquire the numerical data:*
   - Q-Meta-Data: names of different types of methods used to obtain the numerical data.

**Table 8.1 The LCA data set.** *Components, which may or should be part of a complete LCA data set are shown. The practical document, in Figure 8.7, may be compared.*

| | |
|---|---|
| **System Requirement:**<br>- Operational activities.<br>- Operational functions.<br>- Operating requirements.<br>- Mission/use profile.<br>- Maintenance policy.<br>- Reliability, availability and safety requirements.<br>- Environmental requirements, hazardous materials/waste.<br>- Expected total cost of ownership.<br><br>**System Definition:**<br>- General description.<br>- Functional decomposition description.<br>- Functional interfaces and criteria.<br>- Environmental conditions.<br>- Maintenance plan.<br><br>**System Characteristic:**<br>- Performance characteristics.<br>- Physical characteristics.<br>- Effectiveness requirements.<br><br>**Function Definition:**<br>- General description.<br>- Functional decomposition description.<br>- Functional interfaces and criteria.<br>- Environmental conditions.<br>- Maintenance plan.<br><br>**Function Characteristic:**<br>- Performance characteristics.<br>- Physical characteristics.<br>- Effectiveness requirements.<br><br>**Installation Definition:**<br>- General description.<br>- Specific operational requirements.<br>- Functional material part breakdown.<br>- Functional interfaces and criteria.<br>- Environmental conditions. | **Installation Characteristic:**<br>- Performance characteristics.<br>- Physical characteristics.<br>- Capability.<br>- Reliability.<br>- Availability.<br>- Testability.<br>- Maintainability.<br>- Safety and risks.<br>- Energy efficiency.<br>- Recyclability.<br><br>**Technical Data Package:**<br>- Product definition documents.<br>- Handbooks.<br>- Drawings.<br>- Test plans and reports.<br>- Life Cycle Inventory.<br><br>**Product/Service Specification:**<br>- Product audits.<br>- Product documentation.<br>- Quality assurance plan.<br>- Test and evaluation plan.<br>- Contractor data requirements list.<br>- Acceptance standards.<br>- Contract schedule of requirements.<br>- Test and support equipment plan.<br>- Packaging, handling, storage and transportation plan.<br>- Facilities plan.<br>- Eco-indicator Value.<br>- Cost calculations.<br><br>**Actor Specification:**<br>- Knowledge and skills.<br>- Personnel and training plan.<br>- Resource planning.<br>- EMS certification.<br>- Human resource policy/ management.<br>- Cost information. |

## Process description

| | | |
|---|---|---|
| Process | Name: | |
| Class | Name: | |
| | Reference: | |
| Quantitative reference | Type: | |
| | Name: | |
| | Unit: | |
| | Amount: | |
| Technical scope: | | |
| Aggregation type: | | |
| Technology | Short technology description: | |
| | Technical content & functionality: | |
| | Technical picture: | |
| | Process contents<br>Included processes:<br>Intermediate product flows<br>- Source process:<br>- Input & output source:<br>- Input & output destination:<br>- Destination process: | |
| | Operating conditions: | |
| | Mathematical model<br>Formulae:<br>Name of variable:<br>Value of variable: | |
| Valid time span | Start date: | |
| | End date: | |
| | Time-span description: | |
| Valid geography | Area name: | |
| | Area description: | |
| | Sites: | |
| | GIS: | |
| Data acquisition | Sampling procedure: | |
| | Sampling site: | |
| | No. of sites: | |
| | Sample volume<br>Absolute:<br>Relative: | |

## Flows – inputs and outputs

| | |
|---|---|
| Identification number: | |
| Direction (of flow): | |
| Group: | |
| Receiving environment: | |
| Receiving environment specification: | |
| Environment condition: | |
| Geographical location: | |

## Flows – inputs and outputs *(Cont.)*

| | |
|---|---|
| Related external systems<br>Origin of destination:<br>Transport type:<br>Information reference: | |
| Internal location: | |
| Name<br>Substance name:<br>Reference to nomenclature:<br>Name specification: | |
| Property<br>Name of property:<br>Unit of property:<br>Amount of property: | |
| Amount<br>Name:<br>Unit<br>- Symbol:<br>- Explanation:<br>Parameter<br>- Name:<br>- Value: | |
| Mathematical relations<br>Formulae:<br>Name of variable:<br>Value of variable: | |
| Documentation<br>Data collection (methods):<br>Collection date:<br>Data treatment:<br>Reference to data source: | |

## Modelling & validation

| | |
|---|---|
| Intended application: | |
| Information sources: | |
| Modelling principles<br>Data selection principles:<br>Adaptation principles:<br>Modelling constants<br>- Name:<br>- Value: | |
| Modelling choices<br>Criteria for excluding elementary flows:<br>Criteria for excluding intermediate product flows:<br>Criteria for externalizing processes:<br>Allocations performed<br>- Allocated co-products:<br>- Allocation explanation:<br>Process expansion<br>- Process included in expansion:<br>- Process expansion explanation: | |
| Data quality statement: | |
| Validation<br>Method:<br>Procedure:<br>Result:<br>Valitator: | |
| Other information: | |

## Administrative information

| | |
|---|---|
| Identification number: | |
| Registration authority: | |
| Version number: | |
| Data commissioner: | |
| Data generator: | |
| Data documentor: | |
| Data completed: | |
| Publication: | |
| Copyright: | |
| Access restrictions: | |

**Figure 8.7 The ISO 14048 standard LCA data sheet.** *The data sheet, to be filled in according to the ISO 14048 standard, contains 91 entries. Although not all of them are filled in each time, it is clear that a data set represents a considerable work. A more detailed discussion on how to fill in the data entry is found in Baumann and Tillman, 2004.*

### 8.3.3 Data Documenting

During an LCA project, there is much to gain by working consistently with documentation of the data and the study from the beginning of the project.

During the inventory part of an LCA-project, there are several reasons for documenting the data when the modelling choices are made. In general the data set should be documented according to the following criteria.

*Consistent knowledge of each subsystem/production unit threat is included within the studied system.* The documentation requirements serve as a checklist to ensure that all relevant information is acquired of each data set that is included in the study. At the time of the data acquisition the knowledge of the data is generally most extensive. If that knowledge is not documented there is a risk that it will be lost, and it may be difficult or impossible to recreate the knowledge later in the project. For example, a specific interpretation of the data is often done for the actual application. This interpretation should be documented, since a different data user may interpret the data differently.

*Data quality assessment.* The different aspects of data quality may easily be assessed, to ensure that data quality requirements established in the goal and scope is fulfilled.

*Validity check of data.* The documentation allows for different types of review and validity checks to be performed on the data. This is a requirement according to ISO 14041:1998(E).

### 8.3.4 Assuring Data Quality

Several measures should be considered to assure data quality.

In order to *avoid double counting* and *data gaps* a thorough knowledge is required of the content and the scope of each production unit in the study. Each data set that has been included should be clearly defined and explicitly described.

Attention should be paid to the possibility that data documentation criteria may become too detailed and time consuming. However, the time that is spent on documentation is repaid by the advantage of having a well-documented basis for the study during the interpretation and in the reporting and review of the study.

Another obvious advantage of carefully documenting the data is that the *data may easily be reused* in subsequent studies and by other users. The documentation of data will thus facilitate efficient shared use of data and databases, since all relevant information of the technical system and the data is readily available and easily interpretable.

The *interpretation of the result* is facilitated if a thorough knowledge of the data is acquired. Every part of the system studied can be easily checked through the documentation, to understand the reasons for the result. This is necessary to enable a proper assessment and interpretation of the result. Consequently, the risk for erroneous conclusions to be drawn from the result will be reduced.

The *report from the project* is well prepared, if both the choices made in the modelling of the system model and the included production units are consistently documented. Then it would be possible to automatically generate a study report on how the modelling of the composite (technical) system was performed and a description of each of the technical subsystems and finally, the production units as basic elements of the system LCA.

Efficient *review* requires a structured format for reporting, where all relevant information is transparently described. If the reporting of the study and the data is done according to the data documentation criteria, the time needed for review will decrease. This may in the long term decrease the cost to review LCA-studies. This will for example allow the review of an LCA-study used for type III eco-labelling.

## 8.4 Data Transfer

### 8.4.1 Documentation of Data

The documentation of LCA/LCI-data according to the documentation criteria, described above, should allow an assessment of the data and all aspects of data quality. For example, the documentation should enable an assessment of similarities and dissimilarities between different data sets describing similar systems, subsystems or production units. A difference in a specific emission for two similar situations may for instance originate in minor differences in the technology used.

Ideally, the documentation of data should be completed by the person or persons (actors) that are originally acquiring the data. The documentation will in such case only involve a report of the data acquisition procedure. However, in any LCA project generally several different sources of data are used. Often the data is not sufficiently documented in the original source or the documentation is difficult to interpret. Regardless of the source, however, the data should be handled adequately.

### 8.4.2 Working with Secondary Sources

When using data from secondary sources such as different types of written reports, the main part of the work with data involves interpretation and analysis of the material. This is generally a time-consuming task, and in order to avoid duplication of efforts it is important that the work with the interpretation is documented. Otherwise the next data user may have to reinterpret the material before it may be used.

It should also be remembered that any information regarding inconsistencies in the original material and comments by

## Box 8.1 International Standards for Life Cycle Assessment

**The UNEP/ SETAC Life Cycle Initiative**
The United Nations Environment Program (UNEP), and the Society for Environmental Toxicology and Chemistry (SETAC), has launched an International Life Cycle Partnership, known as the *Life Cycle Initiative*, to enable users around the world to put life cycle thinking into effective practice. The Initiative intends to provide reliable information in an accessible format; support good business practices; contribute to continuous improvement; prepare industry for better informed consumers; and ensure worldwide applicability and dissemination.

*http://lcinitiative.unep.fr*

**The DANTES project**
The DANTES project (Demonstrate and Assess New Tools for Environmental Sustainability) was developed by the Swedish competence centre CPM and Akzo Nobel Surface Chemistry, ABB, and Stora Enso in the EU LIFE-Environment programme. The DANTES project attempted to standardise the LCA as well as Environmental Risk Assessment (ERA), which is a systematic procedure for predicting potential risks to human health or the environment; and Life Cycle Cost, LCC, as a tool to calculate the economic costs caused by a product or a service during its entire life cycle. The information below is further developed on the DANTES website.

*http://www.dantes.info/Tools&Methods/Environmentalassessment/enviro_asse_lca_detail.html*

**The ISO 14040 standard for Life Cycle Assessment**
The International Standards ISO 14040-14043 provides principles, framework, and methodological requirements for conducting LCA studies. The framework of LCA includes:

1. *Goal and scope definition:* Defining suitable goal and scope for the LCA study.
2. *Inventory analysis* compiling an inventory of relevant inputs and outputs of a product system.
3. *Impact assessment* evaluating the potential environmental impacts associated with the selected inputs and outputs.
4. *Interpretation* of the results.

LCA considers the potential environmental impacts throughout a product's life cycle from raw material acquisition through production, use and disposal. Examples of categories of environmental impacts included in commercial LCA software tools are resource use, human health and ecological consequences. The limitations of the LCA technique can be overcome by complementing with other tools and methods e.g. Environmental Risk Assessment, ERA.

The LCA study can assist in identification of improvement opportunities for the studied product or service throughout its whole life; decision-making in industry, governmental and non-governmental organizations; selection of relevant environmental performance indicators and adequate measurement techniques; and marketing opportunities for products, e.g. to use LCA data for eco-labelling, Environmental Product Declaration (EPD), etc.

**Goal definition and scope**
*The goal* of the study should include a statement of the reason for carrying out the study as well as the intended application of the results and the intended audience.

*The scope* should describe the depth of the study and show that the purpose can be fulfilled with the actual extent of the limitations. The scope of an LCA shall considered and describe the *function* of the product system, including its functional unit, system boundaries, and the allocation procedures, the type of *impact assessment* methodology and interpretation used, the *data requirements*, and the type of critical review, if any, and type and format of the report required for the study. (In this book treated in Chapter 5).

*Data quality requirements.* Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met, including time-related coverage; geographical coverage; technology coverage; precision, completeness and representativeness of the data; Consistency and reproducibility of the methods used throughout the data collection; Uncertainty of the information and data gaps.

Reusability of data is also highly dependent on sufficient *data documentation*. One example of a format for sufficient environmental data documentation is the LCI data documentation software SPINE@CPM Data Tool and the LCI database SPINE@CPM Database, developed within the CPM collaboration *(http://www.globalspine.com)*, and later ISO/TS 14048 *(http://www.imi.chalmers.se)*. (Treated in this chapter).

**Inventory analysis (LCI)**
LCI comprises all stages dealing with data retrieval and management. The data collection forms must be properly designed for optimal collection. Subsequently data are validated and related to the functional unit in order to allow the aggregation of results. A very sensitive step in this calculation process is the allocation of flows e.g. releases to air, water and land. Most of the existing technical systems yield more than one product. Therefore, materials and energy flows regarding the process must often be

allocated to the different products. This is recommended to be made according to a given procedure:

- Wherever possible, allocation should be avoided.
- Where allocation is not avoidable, inputs and outputs should be partitioned between its different functions or products in a way that reflects the underlying physical relationships between them.
- If the latter is not possible, allocation should be carried out based on other existing relationships (e.g. in proportion to the economic value of products).

The data collection is the most resource consuming part of the LCA. Reuse of data from other studies can simplify the work but this must be made with great care so that the data is representative. The quality aspect is therefore also crucial. See the ISO/TS 14048 and SPINE data formats and Figure 8.7 (treated in Chapter 5 and 8).

**Impact Assessment (LCIA)**
LCIA aims to evaluate the significance of potential environmental impacts using the results coming out from the LCI phase. The ISO14040 suggests that this phase of an LCA is divided into the following steps:

1. Mandatory elements:
   - *Selection of impact categories*, category indicators and characterization models.
   - *Classification*, i.e. assignment of individual inventory parameters to impact categories; Common impact categories are Global Warming, Ozone Depletion, Photooxidant Formation, Acidification and Eutrophication.
   - *Characterisation*, i.e. conversion of LCI results to common units within each impact category, so that results can be aggregated into category indicator results.
2. Optional elements:
   - *Normalization.* The magnitude of the category indicator results is calculated relatively to reference information, e.g. old products constitute the baseline when assigning a new product.
   - *Weighting.* Indicator results coming from the different impact categories are converted to a common unit by using factors based on value-choices.
   - *Grouping.* The impact categories are assigned into one or more groups sorted after geographic relevance, company priorities etc.

The methods that are usually used for LCIA are e.g. EPS (Environmental Priority Strategies), ECO (Ecological scarcity) and ET (Environmental Theme). (Treated mostly in Chapter 6 and 7.)

**Interpretation**
The aim of the interpretation phase is to reach conclusions and recommendations in accordance with the defined goal and scope of the study. The interpretation is to be made iteratively with the other phases. The life cycle interpretation of an LCA or an LCI comprises Identification of the significant issues based on the results of the LCI and LCIA phases of a LCA.; Evaluation of results, which considers completeness, sensitivity and consistency checks; and Conclusions and recommendations.

In ISO 14040 standard it is recommended that a *critical review* should be performed. In addition it is stated that a critical review must have been conducted in order to disclose the results in public.

Interpretation includes screening of the raw data to fish out the most significant of these. It also includes the identification of which missing data are significant. One also needs to assess how good the results and conclusions are. Will they hold even if some input data turn out to be slightly wrong? That is a so-called sensitivity analysis.

Many LCA results appear as a long list of parameter values. These are mostly of interest to chemists who have some knowledge of the properties of each of the substances, and are able to interpret their significance. This should be illustrated by a full table from an LCA.

The interpretation of the LCA study includes the following items:

1. *Dominance analysis (which life stage);* This analysis should point to which life cycle stage dominate the environmental impact for a product, the production, use or wasting phase.
2. *Contribution analysis (which environmental load);* This analysis should point to which kind of impact dominates the environmental load, resource depletion, impact on human health or impact on ecosystems.
3. *Break even analysis (how long for a multi use)*. This analysis should point to how many times a recycled product (e.g. a beverage-container) should be reused before it is environmentally better than using a non-recyclable product once.
4. *Decision-making analysis.* This analysis should point to which of several products or designs should be the better one for production, a comparative analysis.

The interpretation of an LCA is mostly illustrated in Chapter 9 in this book.

the person that has done the interpretation of the material is also valuable for a data user, and should therefore be documented. It should however be clearly stated in the documentation that this type of information regards views of the person responsible for the documentation.

Obviously, there will always be a risk when working with different types of written reports that the original source may be misinterpreted, through misunderstandings, wrongful translation of technical terms, misinterpretation of nomenclature etc. Hence, whenever possible, it is strongly recommended that the person(s) responsible for the original data acquisition should do the documentation or at least review the documentation.

### 8.4.3 Actions to Avoid Miscommunication

Sometimes models of technical systems are remodelled to transform the data into a form that is suited for LCA or to better suit the immediate purpose for which it will be used. For example, data from environmental reports describing an industrial plant may be remodelled into data describing a specific product produced within the plant.

It is then vital that the practitioner thoroughly documents the work and explicitly explains the choices and assumptions that have been made in the remodelling, both to ensure the trust of the original data supplier, that the supplied data has been handled correctly, and to ensure the trust of the commissioner or other parties interested in the result.

Today, it is not uncommon in LCA that practitioners remodels data without explanations or with only implied references. The remodelling may be based on a thorough analysis and interpretation of the original material, but if that is not explicitly described it is impossible to assess the result. Consequently, if the remodelling is not explained, the data is useless.

### 8.4.4 Aggregated LCI Analysis

Aggregated data on large aggregated composite systems are generally difficult to document without loss of vital information. Such systems should preferably be divided into the subsystems of which it consists, thus allowing separate documentation of each individual subsystem. The advantage of this approach is that the composite system will be fully transparent which enhances the flexibility. Parts of an aggregated system may be updated when needed. The system boundaries chosen for the complete aggregate system may also not be applicable in other studies, but parts of the system may be applicable and reused in other studies.

However, if it is not feasible or possible to disaggregate the system, the technical system, the purpose of the study, the system boundaries, use of allocation methods etc. need to be carefully described in order to avoid misinterpretation of data. The person responsible for the documentation should be especially observant on issues that have a large influence on the result. For instance, if the purpose of the study was to compare different alternatives, several systems may have been excluded that were similar in the compared alternatives.

Also, when describing large aggregated systems it is important to clearly state whether or not "general" systems (such as electricity production or transports), or "cradle to gate" systems (such as production systems of materials and consumer goods) are included in the system. Also, what is included within these types of systems should be described.

### 8.4.5 Lacking Information

In some cases it may be difficult to acquire all information that is required by the documentation criteria. Some of the information may be missing or lost in the original material, and it is not feasible (for e.g. economic reasons) or possible (due to e.g. the fact that the information simply is not available) to obtain the information. The fact that the information is missing is however important information for the data user. It should therefore be explicitly stated in the documentation that it has not been possible to obtain the information, and if possible the reason why it was not possible. Otherwise, other actors may think that the information was available, but has been overlooked by the actor responsible for the documentation. The data user may then make new attempts to obtain the information and fail for the same reason.

### 8.4.6 Unambiguous Data Transfer

Data sufficiently documented according to the documentation criteria, as described above, should ideally not need further research for the data user to be able to interpret and correctly use the data. In practice the general ambition for unambiguous data transfer may vary depending on for what the data will be used and within which contextual environment the data will be communicated. The concept of sufficient documentation is thus very much dependent on the application and the receiver of the information.

Data that are only to be communicated within a specific context, e.g. internally within an organisation, generally requires a less detailed description than if the same data will be communicated externally e.g. between a customer and supplier. Within an organisation the users may be assumed to share a common terminology and much information is implicit and more or less general knowledge within the company regarding technology, processes etc. Consequently, such details do not require an explanation within the organisation.

However, when the data is transferred to a different contextual environment the terminology and implicit knowledge

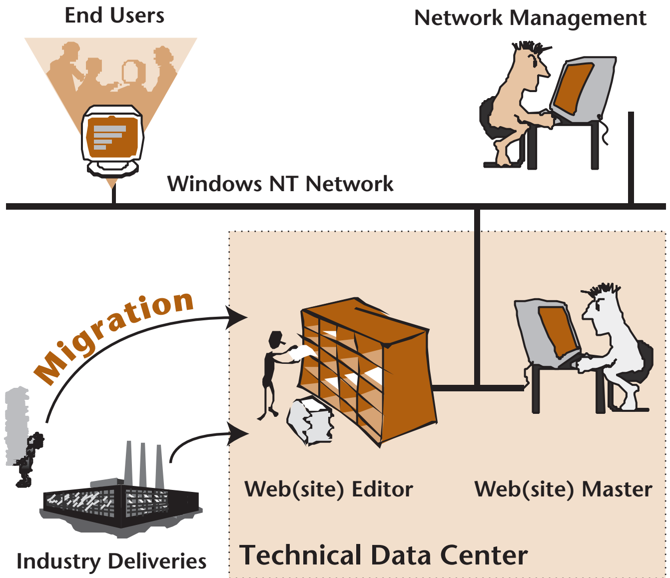



**Figure 8.8 The Product Data Management,** *PDM, environment. The figure illustrates the components in the PDM 2000 Internet environment.*

needs to be explained, in order for the receiver of the information to be able to correctly interpret and use the information. The receiver of the information cannot be expected to have the knowledge that is internal within the company. A general recommendation is therefore that when data is to be communicated externally, a more detailed description may be needed.

Also, documentation of the data constitutes an investment, and depending on how valuable the data is considered, the ambition for the documentation will most likely vary. For example, if it is known that a data set will only be used in a specific application and not communicated, a less detailed description may be sufficient. However, if the data will be reused in many applications and by several users (e.g. be included in a company-internal database) a more detailed description is necessary to avoid further costs for data. And data that has been acquired has a tendency to be reused, even if it was thought at the time of the data acquisition that the data would not be used more than once!

Hence, it may be difficult to know at the time of data documentation, how the data will be communicated and for what the data will be used, other than the intended application for which it was acquired. The actor responsible for the documentation should therefore always aim to provide the prospective data user with all relevant information available at the time of the documentation, thus giving the best possible starting point.

## 8.5 Using Information Technology

### 8.5.1 Product Data Management, PDM

The developments in Information and Communication Technology (ICT) created new opportunities for the PDM approach. One of the new features is the possibility of providing all kinds of data instead of just technical documentation. In particular the wide area network technology and the Internet applications, which connect all actors from top/system level to first production line, have enormous potential.

A web-based PDM approach, based on (proven) Internet and database technologies, is recommended.

The term PDM has been adopted from literature because it is widely recognized and it covers the area of interest quite well. Other terms used in this context are: Asset Information Management (AIM), Through Life Information Management (TLIM), and Electronic Document Management (EDM), etc.

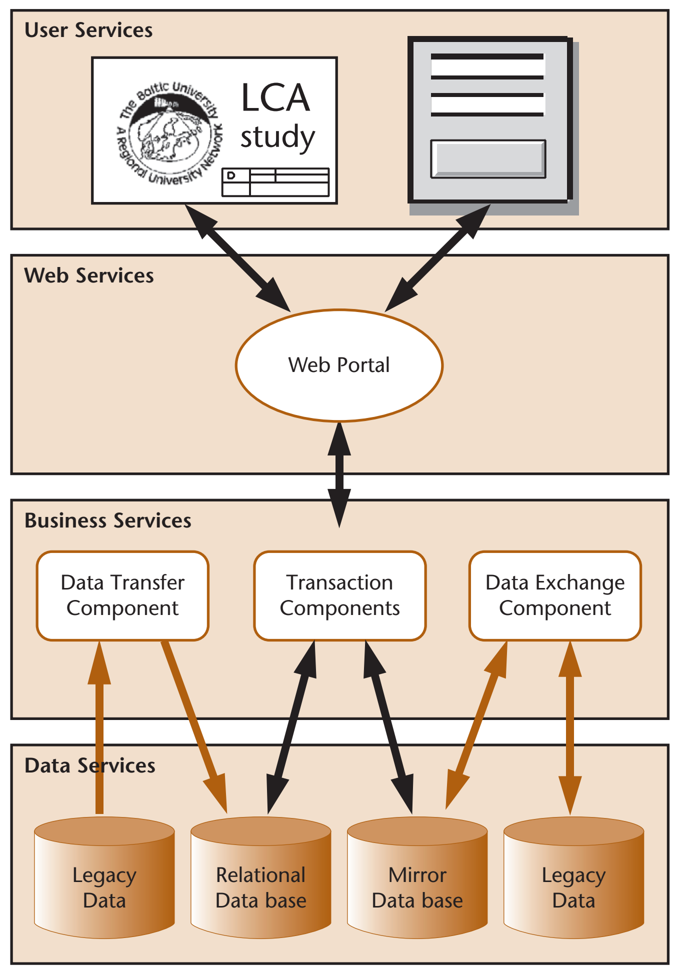



**Figure 8.9 The Product Data Management, PDM, architecture.** *The web-based PDM system architecture consists of four layers.*

## Box 8.2 Life Cycle Assessment Software

*Life Cycle Assessment software has been available since around 1990. Today a series of LCA software and databases are available world-wide, mostly developed by universities and industrial research institutes but also commercially. Below eleven of the most used software packages are briefly described mostly based on the information on the web sites. SimaPro, one of the most established software, is used in the applications in this book. A useful collection of links is available at Tufts University, MA, USA (by Gloria, 2005).*
*http://www.life-cycle.org/lca2.html*

**Boustead** LCA software was developed by Boustead Consulting Ltd. in the UK. The behaviours of industrial processes are modelled by constructing input tables, listing all unit operations that the required process is linked to. The system can easily handle complicated procedures such as networks and closed and open recycling loops.
*http://www.boustead-consulting.co.uk*

**ECO-it**, a Dutch software, models complex products and calculates the environmental load and indicates major contributors quickly, using Eco-indicator 99 and Eco-indicator 95 scores for commonly used materials. ECO-it is a tool for product and packaging designers.
*http://www.pre.nl/eco-it/eco-it.htm*

**EDIP PC-tool** originates from the EDPI (Environmental Development of Industrial Products) project from 1991. It is a cooperation between the Danish EPA, the Technical University of Denmark, and several leading companies. The EDIP PC tool (beta version) uses the ISO 14040 approach and a relational database in SPOLD format.
*http://www.mst.dk/activi/08030000.htm*

**EIO-LCA** (Economic Input-Output LCA), is the joint project of faculty and students at the Green Design Institute of Carnegie Mellon University, PA, USA. The EIO-LCA, applied to a wide range of products and services, provides a wealth of data, summarizing the current U.S. economy in 500 sectors with information on energy and materials use, pollution and greenhouse gas discharges, and other attributes like associated occupational deaths and injuries.
*http://www.eiolca.net*

**GaBi** was developed by the Department of Life Cycle Engineering at the Institute for Polymer Testing and Polymer Science (IKP) at Stuttgart University, Germany. The IKP-GaBi group, together with PE Europe GmbH, is one of the largest groups in Life Cycle and Engineering developing software solutions and databases for use in industrial practice and research. The acronym comes from Ganzheitlichen Bilanzierung – holistic balancing.
*http://www.gabi-software.com*

**IDEMAT** is a software tool for MATerial selections In the DEsign process, developed by Delft University Clean Technology Institute. IDEMAT, which provides a database with technical information about materials, processes and components in words, numbers and graphics, is available in a student and a professional edition.
*http://www.io.tudelft.nl/research/dfs/idemat/index.htm*

**KCL-ECO** was developed by the Finnish pulp, paper and board industries KCL research laboratory at Espoo in 1994. KCL-ECO 4.0 LCA software offers an extensive LCI database Ecoinvent-database. Demoversion available.
*http://www.kcl.fi/page.php?page_id=75*

**LCAiT**, developed at Chalmers University of Technology, Department of Industrial Technology (CIT) in 1992, was then the first software with a graphical interface. LCAiT has been widely used for the environmental assessment of products and processes, already at the design stage. Numerous databases, impact factors and assessment factors can be viewed simultaneously. LCA data is documented in SPINE (Sustainable Product Information Network for the Environment) format.
*http://www.lcait.com/01.html*

**SimaPro**, developed by PRé Consultants Amersfoort, the Netherlands, was first released in 1990. The most recent version is 7.0. SimaPro stands for "System for Integrated Environmental Assessment of Products". SimaPro is used both for product assessment, and analysis of processes and services in accordance with the ISO 14040. It includes extensive filtering options, complex waste treatment and recycling scenarios, allocation of multiple output processes, and analytical features using Monte Carlo analysis. With nearly thousand licensed users in 50 countries, it is a very successful LCA software.
*http://www.pre.nl/simapro/simapro_lca_software.htm*

**TEAM** (Tools for Environmental Analysis and Management) LCA software was produced by the French company Ecobilan, since 2000 part of Pricewaterhouse Coopers. TEAM allows the user to build and use a large database and to model any industrial system representing the operations associated with products, processes and activities using the ISO 14040 series of standards.
*http://www.ecobalance.com/uk_team.php*

**Umberto**, developed by the Institute for Environmental Informatics, ifu, Hamburg and Institute for Energy and Environmental Science, ifeu, Heidelberg, is a powerful software to model, calculate and visualize material and energy flow systems. It is used to analyse the process systems in a plant or a company or along a product life cycle. Results can be assessed using either economic or environmental performance indicators.
*http://www.umberto.de/en/index.htm*

## Box 8.3 Life Cycle Inventory Databases

*Life Cycle Assessment databases have been developed in parallel with the software; the software described on the previous page are almost all connected to databases. In addition a number of special data sets have been developed for LCA. Some of them are general, and others special, for e.g. agriculture, the construction industry or special industrial sectors. Several datasets are available for free. The ISO 14048 is a generally accepted database standard format as are the Danish SPOLD and the Swedish SPINE formats, both compatible with the ISO standard. Below several often used datasets are cited.*
*http://lca-net.com/spold/*
*http://spine.imi.chalmers.se/Spine_EIM/spine.htm*

Useful collections of database: **US EPA Global LCI Directory**, the **University of Washington Inventory of Inventory Sources** and the **U.S. Life-Cycle Inventory (LCI) database** of the National Renewable Energy Laboratory (NREL).
*http://www.epa.gov/ORD/NRMRL/lcaccess/dataportal.htm*
*http://faculty.washington.edu/cooperjs/Definitions/inventory%20squared.htm*
*http://www.nrel.gov/lci/database/default.asp*

Swedish National LCA database **SPINE@CPM** was formed through a joint research forum between 13 industrial corporations and Chalmers University of Technology forming the CPM (Center for Environmental Assessment of Product and Material Systems). The public version of the SPINE@CPM LCI database contains more than 500 well-documented LCI data sets in the ISO/TS 14048 compatible SPINE format. SPINE addresses five different information areas; identification of technical systems, methods used to obtain the data set, details on data acquisition, flows of material and energy, and recommendations for using the data. Search categories are (1) material outputs and inputs for product outputs, any material and energy output, and material inputs and (2) unit processes and product systems for process names, transport, system scopes, and sectors.
*http://publicdb.imi.chalmers.se/imiportal/*
*http://www.globalspine.com*

**CML-IA** is a database from the Institute of Environmental Sciences (CML) Department of Industrial Ecology of Leiden University. It contains Eco-indicator 99 and EPS, normalization data for all interventions and impact categories at different spatial and temporal levels. Data is supplied in MS-Excel, and can be downloaded free of charge.
*http://www.leidenuniv.nl/cml/ssp/*

The **IVAM** database, produced by IVAM consultancy, originating from University of Amsterdam's Environmental Science Department, consists of about 1350 processes, leading to some 350 materials, such as construction materials (plastics, metals and others), agriculture (e.g. milk, fish, meet, feed, fertiliser, pesticide), electrical industries (e.g. PV-panels) and waste treatment (23 waste types and six processing alternatives). The nomenclature is adapted to SimaPro 6 format Standard database.
*http://www.ivam.uva.nl/uk/*

Ecobilan's Waste Management LCA software tool **WISARD** (Waste-Integrated Systems for Assessment of Recovery and Disposal) compiles large life cycle inventories for waste management scenarios using Ecobilan data, input data, or a combination.
*http://www.ecobalance.com/uk_wisard.php*

**SALCA** (Swiss Agricultural Life Cycle Assessment) produced by the Swiss Federal Research Station for Agroecology and Agriculture Zurich-Reckenholz, provides a database, updated and used for key agricultural systems.
*http://www.reckenholz.ch/doc/en/forsch/control/bilanz/bilanz.html*

**CRMD** (The Canadian Raw Materials Database) involves a cross-section of Canadian commodity materials industries to and inputs and outputs of aluminum, glass, plastics, steel and wood.
*http://crmd.uwaterloo.ca/*

Swiss National LCI Database **EcoInvent** is produced by the Swiss Centre for Life Cycle Inventories with Swiss Federal Institutes of Technology Zürich (ETHZ) and others. Registration is required to access the Ecoinvent database. The Ecoinvent database system allows central compilation, management, calculation and access to life cycle inventory data via the Internet. Data covers energy, transport, waste treatment, buildings, chemicals, detergents, graphical papers and agriculture; the geographic scope of the supply situation covers Switzerland and Western Europe. Also occasional guests may carry out simple or advanced searches on the complete Ecoinvent database content.
*http://www.ecoinvent.ch/en/index.htm*

The **LCA National Project in Japan** funded by the Ministry of Economy, Trade and Industry (METI) contain LCA methodologies and LCA data for Japan. LCI data for approximately 200 products were collected based on Gate to Gate, by some 50 industrial associations.
*http://lcacenter.org/InLCA-LCM03/Narita-abstract.pdf*

**Australian Life Cycle Inventory Data Research Program** develops detailed data inventory resources for Australia. The data are published in spreadsheets, and are also available in SimaPro LCA software, without costs.
*http://auslcanet.rmit.edu.au/datapage.html*

**LCA Food Database Denmark** is a result of a project by the Danish Institute of Agricultural Sciences, and several research institutes in the area. Data are available in the LCA tool SimaPro, without costs.
*http://www.lcafood.dk/lcamodel.htm*

### 8.5.2 Web Based Product Data Management (PDM 2000)

The PDM 2000 approach is primarily based on standard Internet applications. On the basis of these applications an LCA Internet environment can be constructed. Figure 8.8 illustrates the environmental design.

In the Technical Data Center (TDC) all data is collected, classified and edited in the correct LCI data layouts.

In Figure 8.9 the ICT services needed are illustrated in four different layers.

### 8.5.3 Web Based PDM Systems

In the previous paragraphs the information and communication structure has been explained along with the PDM approach. This approach is generally applicable because it allows considerable freedom to change and choose specific data and information structures at any moment. This is due to the flexibility of the selected ICT architecture combined with the ASP-based (Active Server Pages) Data Base Interface Engine.

The use of principles such as Active Server Pages makes the user interface very flexible and provides the opportunity to use it also as 'user information request form'. This kind of web page technology offers a free choice in web page design and in ways of combining various data, stored in different databases. Within the guidelines of the organisation and/or method, users can design and structure their own technical web site and information pages.

For demonstration a simple demo of a web PDM system portal is available on the CD.

## Study Questions

1. What are the two most important questions to answer with regard to developing an Information Management System?
2. What are the four specific information management objectives to define? List them as they appear in the development of an IMS.
3. Describe an LCI and its basic elements.
4. What are the most important components of Data Quality? List and comment on them.
5. How would you set up a conceptual LCA data set of a simple article like a coffee machine? What are the most important issues with regard to Data Transfer?

## Abbreviations

| | |
|---|---|
| CPM | Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology. |
| LCI | Life Cycle Inventory. |
| PDM | Product Data Management. |
| SPINE | A database format developed at CPM. |
| SPOLD | A database format (Society for Promotion Of Life-cycle assessment Development). |
| TDC | Technical Data Centre. |

## Internet Resources

Chemical Abstracts Service training database
http://www.cas.org/ONLINE/DBSS/lcass.html

PE Europe GmbH, IKP from the University of Stuttgart, and GaBi4 software with databases
http://www.environmental-expert.com/software/pr_eng/pr_eng.htm

Industrial Environmental Informatics (IMI), Chalmers University of Technology Databases
http://databases.imi.chalmers.se

Global spine: Industrial environmental data and information, Chalmers University of Technology
http://www.globalspine.com/

Centre for Environmental Assessment of Products and Material Systems (CPM), Chalmers University of Technology
http://www.cpm.chalmers.se/freetools.htm

PRé Consultants: Eco-indicator 95 impact assessment & ecodesign method
http://www.pre.nl/eco-indicator95/

PRé Consultants: Eco-indicator 99 impact assessment & ecodesign method
http://www.pre.nl/eco-indicator99/

The MIPS database
http://www.wuppertalinst.org/Projekte/mipsonline/index.html

The SPOLD database at 2.-0 LCA consultants, Copenhagen.
http://lca-net.com/spold/

The AMC Windfarm project System Portal as web based PDM demo
http://www.amccentre.nl/harakosanDemo/

# 9 Applying LCA – Comparing two Windows

## 9.1 Prerequisites

### 9.1.1 The Objective of the Study

In this chapter Life Cycle Assessments and a comparison of environmental profiles of two products (comparative LCA) will be made to illustrate all steps necessary to perform a full-scale LCA in practice using the previously described methodology.

The aim of the analysis is to check which of the two products, a PVC or an aluminium framed window, is more advisable from an environmental point of view. Moreover, we should also determine which life stages and processes constitute the majority of the environmental burden associated with the two products.

The main objective of the study is educational. The results of the analysis should thus not be used externally, e.g. for commercials or marketing claims. However, the results could be interesting for producers of windows who want to diminish the environmental consequences of their activity, as well as clients of building firms, or non-governmental organisations intending to influence the public, etc.

The analysis has been conducted using SimaPro 5.0 software with the application of the SimaPro Eco-indicator 99 database and different indicators, available in SimaPro methods library as one of the most universal applications. It should be stressed, however, that relying on one single database is a significant limitation of the analysis.

When summarising the results of the LCA, it should be emphasised that performing an LCA is a complex task. In its initial phase it requires a careful life cycle inventory and the collection and correction of data. Good data quality is a precondition for a reliable outcome. The necessity of introducing simplifying assumptions and the lack of standard methodology, especially for the normalisation and weighting phases, make the final result of the LCAs described here unsuitable for commercial applications.

**In this Chapter**

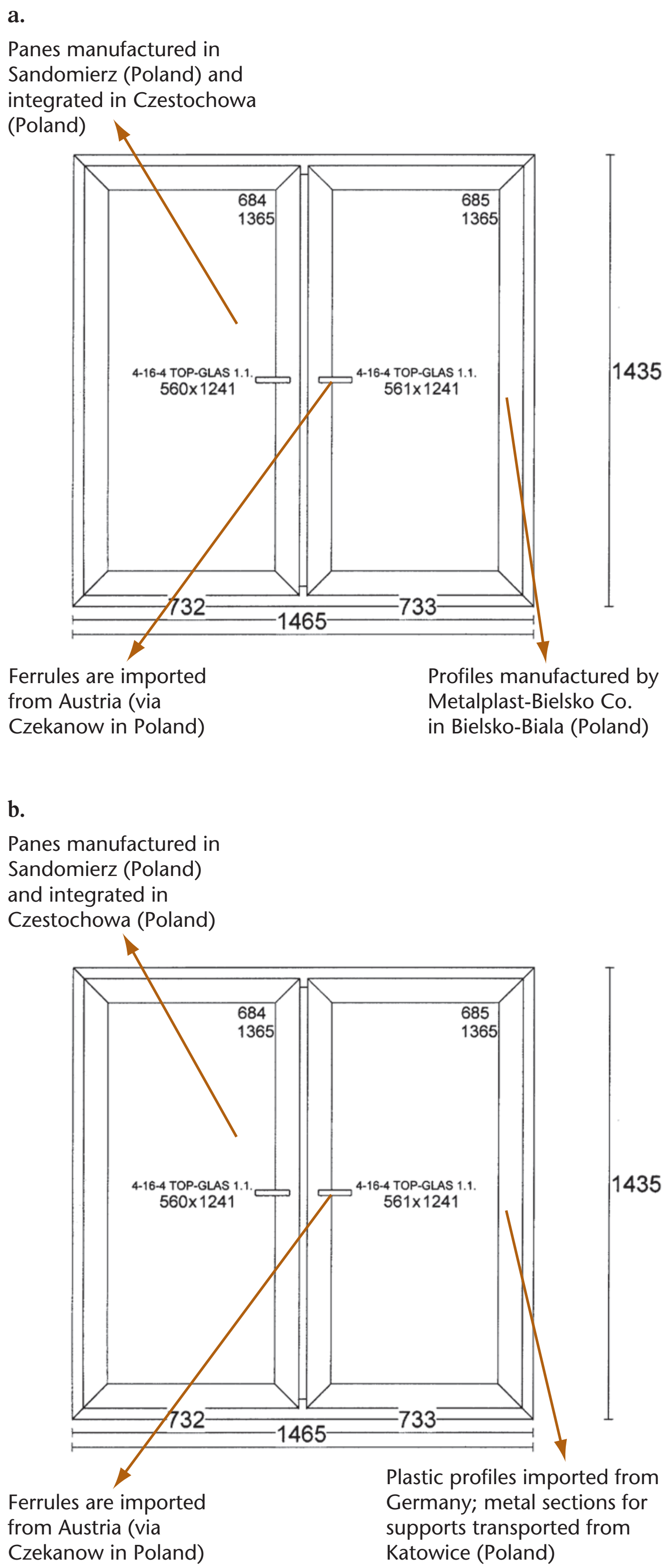



**Figure 9.1 Basic data for the two windows. a.** *The aluminium frame window.* **b.** *The PVC (polyvinyl chloride) frame window.*

### 9.1.2 The Windows

The aluminium frame window, the *Alu window*, with basic technical information is shown in Figure 9.1a, and the plastic frame *PVC window* (PVC = polyvinyl chloride) with basic technical information in Figure 9.1b. We will first go through the entire analysis for the aluminium window and then do the same with the PVC window. We will end with a discussion of how the results from the two analyses can be compared, and draw conclusions.

To start the LCA analysis, a *functional unit* must be defined. The functional unit has been defined as a symmetrical window with two sashes which can be installed in the outside wall of a building (this means that an aluminium window has to have a thermal barrier); dimensions: 1465x1435 mm. Lengths of life have been estimated to be 40 years for the plastic window and 50 years for the aluminium window. As a result of the different length of life, in the LCA analysis 1.0 aluminium window will be compared with 1.25 PVC windows, (50/40 = 1.25).

The windows are both considered to be produced and used in the area of Lodz in central Poland. This is important for the calculation of the environmental impact from the transport of materials to the windows.

## 9.2 The Aluminium "ALU" Window LCA

### 9.2.1 Life Cycle Inventory

The first step of LCA is to perform a Life Cycle Inventory. Figure 9.2 shows all inflows and outflows for all life cycle phases which were taken into account in the analysis. All the technical data were derived from one of the companies installing windows in Lodz, Poland. Basic technical data collected for the LCA analysis of the aluminium window are given in Table 9.1.

The total mass of an aluminium window is 63.55 kg. Of this, 25.4 kg is the weight of the aluminium profiles (24.9 kg) and handles (0.5 kg). The aluminium profiles are produced by Metalplast-Bielsko Co., Poland, in an extrusion process. (Extrusion means that something is formed by forcing or pushing it out, especially through a small opening, i.a. used for aluminium materials, e.g. extruded aluminium rods.) The transport distance from Bielsko to Lodz is 254 km.

Ferrules and anchors, comprising 2.75 kg of high quality steel, were imported from Austria via Czekanów (transport distance 600 km).

The *float* type glass used, a total of 30.4 kg, was produced in Sandomierz (Poland). It is integrated hermetically into window panes in Czestochowa (transport distance 320 km).

Other materials, a total of 5.5 kg, are plastic, including the polyamide thermal barriers and the gaskets of ethylene-propylene rubber (EPDM).

During 50-year use, the window is assumed to require two replacements of ferrules (about every 20 years) and four replacements of gaskets (every 10 years). These elements have their own life cycles. The replaced ferrules are scrapped and gaskets are discarded. We assume that the window is dismounted after 50 years. Aluminium elements, handles, ferrules, anchors and window panes can be recycled. The rest, i.e. gaskets and the thermal barrier, are discarded, partly incinerated and partly land filled (according to a Dutch scenario of municipal waste utilisation). Instead of dividing the transport according to particular groups of objects, it is assumed that the whole window is transported a distance of 50 km.

Due to the lack of sufficient data, the following operations have been neglected in the analysis:

- Window cleaning.
- Powder coating of the aluminium profiles with the chromated polyester lacquer.
- Joining the elements with glue.
- Filling the cracks between the window and the wall with polyurethane foam and glass fibre and sealing them with silicone.
- Elements necessary for glass integration (small amounts of butyl, thioplast and aluminium frames).

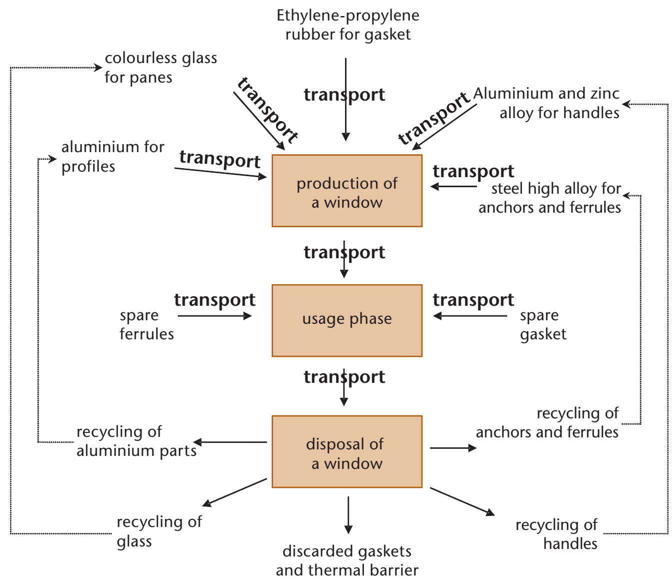



**Figure 9.2 Inventory of inflows and outflows.** *The inventory diagram for the life cycle of the aluminium frame window.*

**Table 9.1 Technical data for LCA of the aluminium window.** *Data for aluminium profile made of aluminium alloy $AlMgSiO_5$ with a thermal barrier made of polyamide strengthened with glass fibre (PA 6.6). The thermal barrier is estimated to be 10% of the mass of the profile with the thermal barrier consisting of frame, muntin and sashes. The weight of the gasket is estimated to be 0.015 kg/running meter. The glass is estimated to be 1 mm thick and have a total weight of 2.5 kg/m². The weight of the ferrule is estimated to be 2.5 kg and the anchors 0.25 kg.*

| **Aluminium profiles** | | | |
|---|---|---|---|
| Element | Length (m) | Mass/metre (kg) | Mass (kg) |
| Frame | 5.8 | 1.6 | 9.28 |
| Muntin | 1.367 | 0.79 | 1.08 |
| Sashes | 8.29 | 1.75 | 14.51 |
| Other elements (estimated) | | | 2 |
| Thermal barrier | | | 2.5 |
| Total | | | 29.37 |

| **Other elements and accessories** | | | |
|---|---|---|---|
| Name | Material | Quantity | Mass (kg) |
| Gasket | Ethylene-propylene rubber (EPDM) | ~ 32 m | 0.5 |
| Panes | Colourless glass | Two double integrated panes 4/16/4 of size 594x1279. | 30.4 |
| Ferrules and anchors | High-quality steel | 1 set | 2.75 |
| Handles | Aluminium and zinc alloy (ZnAl) | 1 set | 0.5 |
| Total | | | 34.15 |

## 9.2.2 Process Trees

The next step in the LCA is to generate a *process tree* (Figure 9.3) on the basis of the inventory analysis and all available technical information (Table 9.1). Figure 9.3a illustrates a full process tree of an aluminium window produced by SimaPro. The grey boxes in the figure schematically represent subsequent technological processes grouped into life phases (production, usage, disposal).

The database used to elaborate the life cycle of the aluminium window and the process tree is part of the SimaPro software. The inventory table consists of 595 items, which illustrates the huge number of inflows and outflows connected with an aluminium window life cycle. Selected items of this inventory table are shown in Table 9.2. Accessing, collecting, and interpreting this amount of data is one of the biggest challenges encountered in an LCA process. The figure shows how complex a process tree can be even for such a simple object as a window.

To make a picture of an LCA process more transparent, certain processes, inflows and outflows can be grouped and represented by only one box. Such a *simplified process tree* can be generated by SimaPro (and most other LCA software packages). The simplified process tree for an aluminium window (Figure 9.3b) includes environmental indices of the life cycle phases calculated according to Eco-indicator 99 method. The thickness of lines graphically illustrates the level of environmental impact of the particular processes constituting the life cycle of the window. Brown lines with arrows in the reverse direction reflect the waste utilisation process, energy recovery, and recycling, etc., in the product life cycle. Negative values in the boxes result from the fact that emissions avoided due to recycling or energy recovery have been subtracted from the total environmental impact.

In Figure 9.4 a single element, a *process box*, of the process tree is described. Each process box contains the following information:

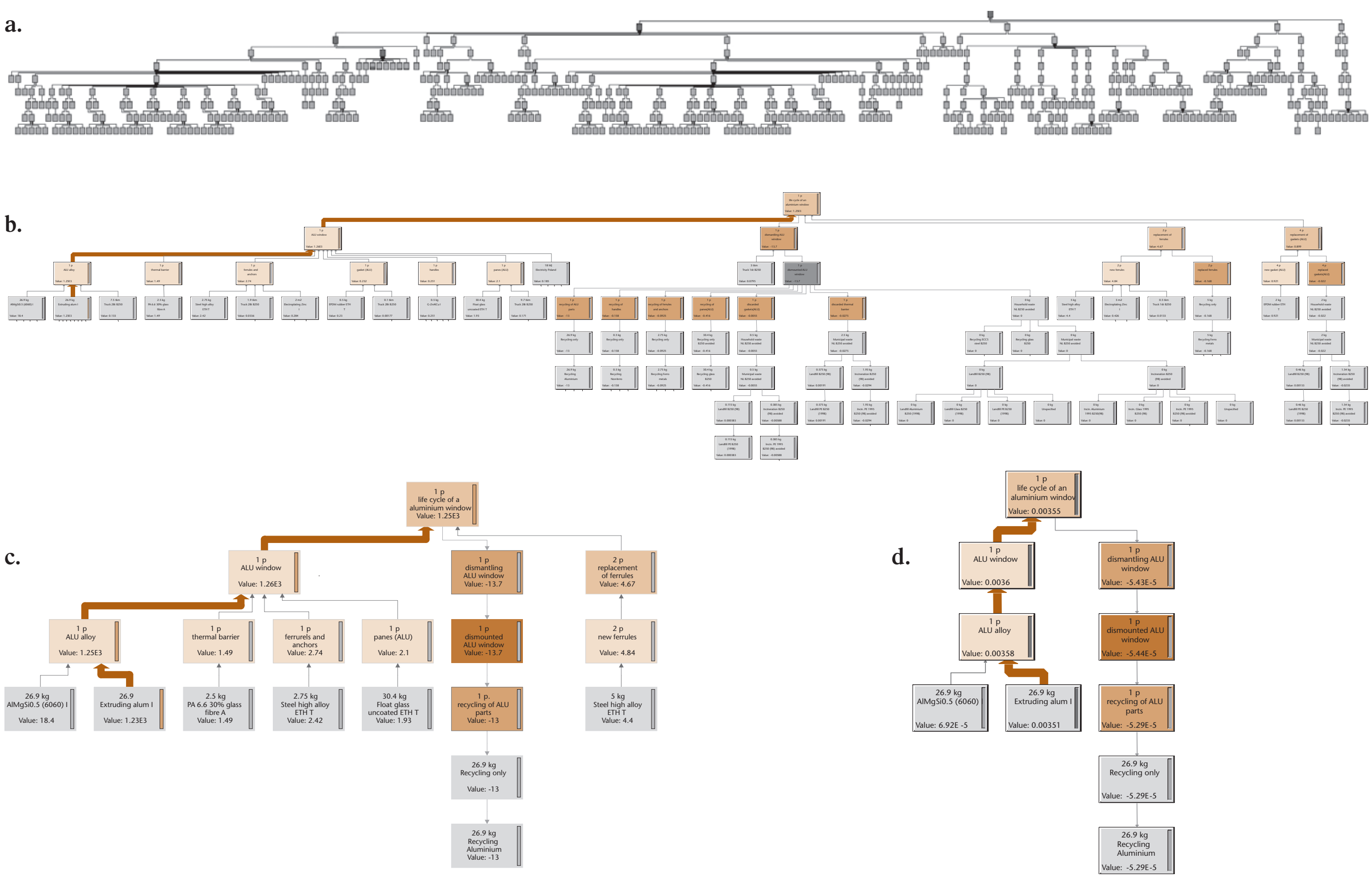



**Figure 9.3 Process trees for and LCA of the aluminium frame window. a.** *Full process tree for a life cycle of the aluminium frame window generated by SimaPro.* **b.** *Simplified process tree in which several processes are grouped into one box. This includes environmental indices calculated according to Eco-indicator 99. The thickness of the lines is proportional to the environmental impact.* **c.** *Simplified process tree in which only elements with an environmental index larger that 0.1% are included.* **d.** *Simplified process tree in which only elements with an environmental index larger that 1% for the impact category climate change are included.*

- The value of the calculated quantity (partial environmental index, selected emissions, normalised or weighted damage indicators, etc.).
- The quantity (in pieces, kilograms, litres, etc.).
- The name of the material.
- The process of life stage (e.g. aluminium alloy, truck, high steel alloy, etc.).
- The environmental “thermometer”.

The process box shows how to calculate two important parameters, the environmental index and the environmental “thermometer”. The index shows the impact of the element in the tree. The “thermometer” indicates the relative contribution of the calculated quantity to a single score, to an impact category or a single emission. E.g. when you select $CO_2$ emissions, the thermometer will display the relative contribution of the process to the $CO_2$ emissions in the whole life cycle.

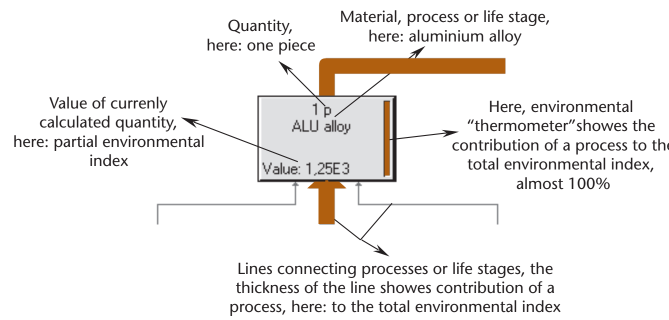



**Figure 9.4 A process box for the calculation of an environmental index.** *The calculation is made for an item in the life cycle of the aluminium frame window. The process box contains the life stage, the material, the quantity, the environmental index for that impact, and the thermometer showing the contribution of the process to the total environmental index.*

**Table 9.2 Inventory table for the life cycle of the aluminium frame window.** *The table is generated by the SimaPro software and its database and contains 595 entries.*

| No | Substance | Comp | Unit | Total | ALU window | dismantling ALU wi | replacement of ferr | replacement of gas |
|---|---|---|---|---|---|---|---|---|
| 1 | acids | Raw | kg | 0 | x | 0 | x | x |
| 2 | additions | Raw | g | -47,5 | x | -47,5 | x | x |
| 3 | additives | Raw | kg | 0 | x | 0 | x | x |
| 4 | air | Raw | oz | 109 | 117 | -2,76 | -5,03 | x |
| 5 | alloys | Raw | kg | 0 | x | 0 | x | x |
| 6 | aluminium (in ore) | Raw | kg | 4,04 | 4,04 | x | x | x |
| 7 | auxiliary materials | Raw | kg | 0 | x | 0 | x | x |
| 8 | barrage water | Raw | tn.lg | -113 | x | -113 | x | x |
| 9 | baryte | Raw | oz | 77,3 | 76,1 | 0,0576 | 0,644 | 0,499 |
| 10 | bauxite | Raw | lb | -90,3 | 190 | -286 | 5,2 | 0,00373 |
| 11 | bentonite | Raw | oz | 103 | 101 | 0,0608 | 1,94 | 0,0673 |
| 12 | boron (in ore) | Raw | mg | 684 | 684 | x | x | x |
| 13 | calcium sulphate | Raw | mg | 19,3 | 19,3 | x | x | x |
| 14 | calumite | Raw | g | -439 | x | -439 | x | x |
| 15 | chalk | Raw | pg | 3,12E-13 | 3,12E-13 | x | x | x |
| 16 | chromium (in ore) | Raw | g | 1,37E3 | 574 | 0,0808 | 800 | 0,07 |
| ⋮ | | | | | | | | |
| 146 | CFC-116 | Air | mg | 981 | 955 | 0,139 | 25,7 | 0,0184 |
| 147 | CFC-12 | Air | µg | 26,5 | 10,7 | x | 11,6 | 4,2 |
| 148 | CFC-13 | Air | µg | 16,6 | 6,75 | x | 7,25 | 2,64 |
| 149 | CFC-14 | Air | g | 8,79 | 8,56 | 0,00112 | 0,231 | 0,000166 |
| 150 | CFC (soft) | Air | µg | 532 | 532 | x | x | x |
| 151 | Cl2 | Air | mg | 99,4 | 99,4 | x | x | x |
| 152 | CO | Air | oz | 132 | 148 | -18,2 | 2,22 | 0,209 |
| 153 | CO2 | Air | kg | 1,53E4 | 1,55E4 | -257 | 32,5 | 9,74 |
| 154 | cobalt | Air | mg | 897 | 891 | 0,518 | 4,46 | 1,14 |
| 155 | Cr | Air | mg | 807 | 802 | 0,501 | 4,54 | 0,727 |
| 156 | CS2 | Air | ng | 380 | 380 | x | x | x |
| 157 | Cu | Air | g | 2,47 | 2,17 | 0,00125 | 0,302 | 0,00218 |
| 158 | CxHy | Air | oz | 311 | 339 | -22,4 | -5,76 | x |
| 159 | CxHy aromatic | Air | mg | 190 | 348 | -123 | -27,8 | -7,19 |
| ⋮ | | | | | | | | |
| 284 | COD | Water | oz | -34 | 1,7 | -35,7 | 0,0274 | 0,0468 |
| 285 | Cr | Water | g | 31,8 | 30,3 | 0,00881 | 1,47 | 0,00939 |
| 286 | Cr (VI) | Water | mg | 7,98 | 7,94 | 0,00454 | 0,0322 | 0,00238 |
| 287 | crude oil | Water | g | 93,2 | 93,3 | -0,0304 | -0,0205 | x |
| 288 | Cs | Water | mg | 24,2 | 23,8 | 0,0134 | 0,157 | 0,162 |
| 289 | Cu | Water | g | 14,9 | 14,7 | -0,00172 | 0,18 | 0,00596 |
| 290 | CxHy | Water | g | 621 | 620 | 0,273 | 0,462 | 0,000436 |
| 291 | CxHy aromatic | Water | g | 14,6 | 14,4 | -0,0268 | 0,1 | 0,0938 |
| 292 | CxHy chloro | Water | mg | 13,1 | 13,1 | 0,0159 | 0,0363 | -0,0035 |
| 293 | cyanide | Water | mg | 228 | 204 | 0,0119 | 23,2 | 0,558 |
| 294 | detergent/oil | Water | mg | 103 | 103 | x | x | x |
| ⋮ | | | | | | | | |
| 403 | rejects | Solid | kg | 0 | x | 0 | x | x |
| 404 | slag | Solid | oz | 298 | 298 | 0 | 0,000287 | x |
| 405 | slags/ash | Solid | kg | 23,9 | 23,9 | x | x | x |
| 406 | soot | Solid | g | 11,7 | 11,7 | x | x | x |
| 407 | steel scrap | Solid | g | 388 | x | 138 | 250 | x |
| 408 | tinder from rolling drum | Solid | kg | 0 | x | 0 | x | x |
| 409 | unspecified | Solid | g | 6,18 | 6,18 | x | x | x |
| ⋮ | | | | | | | | |
| 592 | Zn65 to air | Non mat. | µBq | 698 | 283 | x | 304 | 111 |
| 593 | Zn65 to water | Non mat. | mBq | 129 | 52,9 | x | 55,5 | 20,2 |
| 594 | Zr95 to air | Non mat. | µBq | 10,4 | 4,23 | x | 4,54 | 1,65 |
| 595 | Zr95 to water | Non mat. | mBq | 808 | 328 | x | 352 | 128 |

The simplification of the process tree in Figure 9.3b is a formal graphical representation of many processes in one box. The next steps in the LCA analysis require further *decomposition of the process tree* with respect to the importance of the environmental effects. The process tree can thus be simplified by performing a contribution analysis, in which processes of minor environmental importance are disregarded. As an example of decomposition, a process tree which includes only those processes which constitute more than 0.1% of the environmental index for the whole life cycle is shown (Figure 9.3c).

Application of other environmental criteria, e.g. damage category, impact category, etc. and the assumption of another level of environmental impact e.g. 0.5%, 1%, etc., leads to different forms for the process tree. As an example, Figure 9.3d shows a process tree for an aluminium window where the impact category is *Climate change* and the cut-off level 1%. For this category Eco-indicator 99 uses DALY (Disability Adjusted Life Years) as a unit which expresses damage to human health.

A comparison of Figures 9.3a to 9.3d shows different but complementary aspects of the life cycle of the aluminium window.

### 9.2.3 Analysing Process Trees

An analysis of all the process trees shows that extrusion of aluminium causes that the most important environmental impact. Its contribution to the total environmental load is over 95% in almost each impact category (compare the thickness of the lines in Figures 9.3c to 9.3d). In such a situation, when one process strongly dominates, the process tree can be considerably simplified (Figures 9.3c to 9.3d) which enables easier and more clear LCA.

### 9.2.4 Characterisation – Impact and Damage Categories

The next step in the LCA analysis is *characterisation*. This groups inflows and outflows into impact categories.

Inflows and outflows in the life cycle of an aluminium window were grouped in 11 impact categories according to the methodology of Eco-indicator 99. The characterisation shows the relative strength of the unwanted environmental impacts and their contributions to each environmental problem. Computational procedures used for aggregating the data into impact categories apply environmental models to compare different contributions to the same environmental problem. This task can be achieved using *equivalence factors* provided by the models.

An analysis of an inventory table for an aluminium window allow us to determine which substances contributes most importantly to each impact category. The 11 impact categories, each with the respective material from the life cycle of the ALU window, are as follows:

*Carcinogens:* these are mainly nickel, arsenic and cadmium as well as other metals released to water and air connected with electricity needed for extruding aluminium profiles, which is based on hard coal.

*Respiratory substances:* VOC (Volatile Organic Compounds) emissions, sulphur dioxide and nitric oxides resulting from aluminium alloy production, electricity generation and extrusion of aluminium.

*Climate change:* $CO_2$, $NO_2$ and methane emissions arising during aluminium extrusion and electricity production required for this process.

*Radiation:* Replacement of ferrules is of the highest significance, then, in turn, the manufacturing stage and the replacement of gaskets, which are connected with isotope emissions, mainly $^{14}C$ to the air and $^{137}Cs$ to water. The greatest contributions are ascribed to steel high alloy used in ferrule production and synthetic rubber for gaskets, both in the manufacturing life stage. For the production phase the outcome is presented as the summary contribution, whereas in the case of ferrules and gasket replacements, it is multiplied accordingly by 2 and 4 (multiple replacements during the entire life cycle).

*Ozone layer:* The outcome is almost entirely derived from HALON-1301 ($CF_3Br$) emitted in conjunction with electricity generation.

*Ecotoxicity:* mainly airborne emission of nickel and other metals caused by electricity production.

*Acidification/eutrophication:* nitric oxides and sulphur dioxide emissions connected with the extrusion of aluminium profiles and electricity production.

*Land use:* In this impact category the most important factor is the production of nuclear energy which is used as part of the electricity needed for aluminium extrusion.

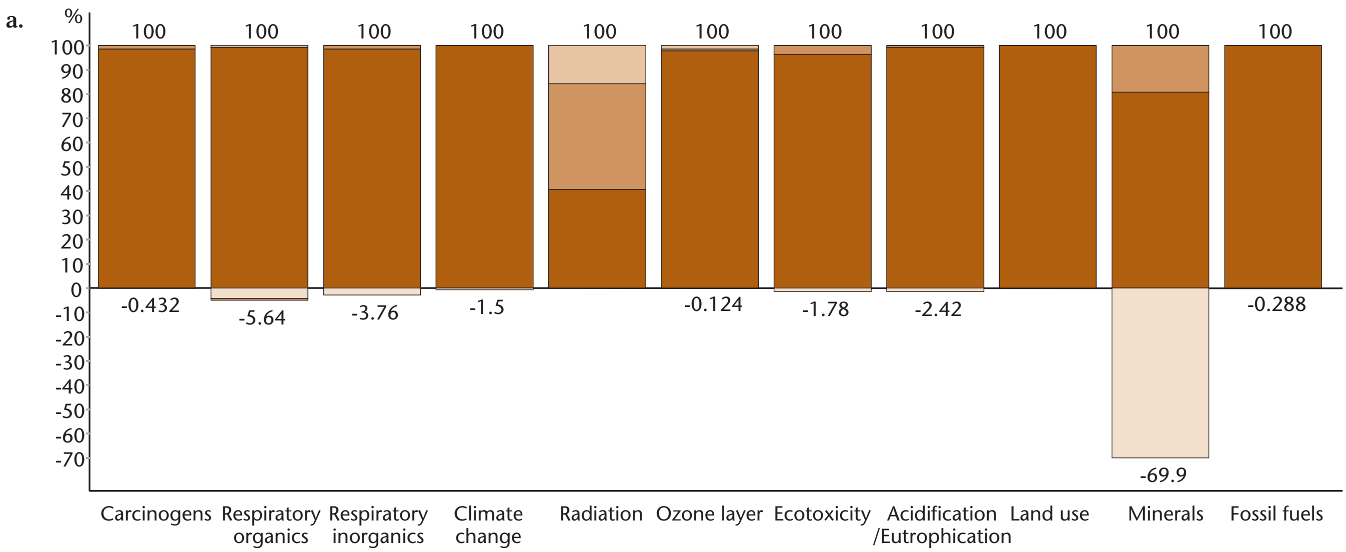
*Minerals:* Minerals depletion is influenced mainly by the production of aluminium alloy, out of which profiles are extruded, and higher quality steel for ferrules. Aluminium recycling is also of high significance. Aluminium scrap is treated as a raw material in aluminium production (such as bauxite). The environmental burden of the bauxite ore extraction is subtracted since it is avoided due to recycling.

*Fossil fuels:* Most of the fossil fuels (mainly crude oil and natural gas) are used in aluminium extrusion.

The characterisation thus amounts to a quantitative analyses of the effects of each phase of the life cycle for each impact category. The results are absolute values of impacts expressed in so-called effect scores or indices (Table 9.3). These constitute the environmental profile of the aluminium window.

**Table 9.3 Environmental profile of the aluminium frame window.** *The table shows the impact for each of 11 impact categories, generated by the SimaPro software. The results are expressed as effect score in DALY (Disability Adjusted Life Years) for categories influencing human health, in PDF (Potentially Disappeared Fraction) for categories influencing biodiversity and MJ (Mega Joules for surplus energy required for future acquisition) for resource consumption categories. The results are given for each of four life cycle processes, as well as the sum for the whole life cycle.*

| Impact category | Unit | Total | ALU window | dismantling ALU wir | replacement of ferru | replacement of gask |
|---|---|---|---|---|---|---|
| Carcinogens | DALY | 0,00113 | 0,00112 | -4,91E-6 | 1,32E-5 | 1,73E-6 |
| Resp. organics | DALY | 1,67E-5 | 1,76E-5 | -8,27E-7 | -1,69E-7 | 7,62E-8 |
| Resp. inorganics | DALY | 0,00895 | 0,00919 | -0,00035 | 0,000107 | 4,07E-6 |
| Climate change | DALY | 0,00355 | 0,0036 | -5,43E-5 | 7,55E-6 | 2,15E-6 |
| Radiation | DALY | 9,88E-8 | 4,01E-8 | x | 4,31E-8 | 1,57E-8 |
| Ozone layer | DALY | 1,48E-6 | 1,44E-6 | -1,84E-9 | 1,61E-8 | 1,65E-8 |
| Ecotoxicity | PAF*m2yr | 958 | 944 | -17,3 | 29,5 | 2,08 |
| Acidification/ Eutrophication | PDF*m2yr | 321 | 326 | -7,94 | 2,19 | 0,12 |
| Land use | PDF*m2yr | 598 | 597 | 0,169 | 0,716 | 0,135 |
| Minerals | MJ surplus | 28 | 74,9 | -65 | 18 | 0,036 |
| Fossil fuels | MJ surplus | 2,53E4 | 2,53E4 | -73,1 | 30,3 | 19,7 |




The results of the characterisation phase, shown as the relative significance of the life stages expressed in percent, is found in Figure 9.5a. The point of reference, 100%, is set equal to the sum for the entire life cycle. It is clear that the most important phase in the life cycle of an aluminium window is the manufacturing phase (dark brown colour). The impact of this phase covers almost 100% of the environmental load in 9 categories. It is caused by the high energy consumption in the aluminium extrusion process, emissions released in conjunction with electricity production, etc. Only in the impact categories *radiation* and *minerals* did the use phase and disposal phase show significant environmental impacts. Impacts in the use phase were caused by replacement of ferrules and gaskets, and in the disposal phase by the dismantling the ALU window. Note that the negative value of the impact in disposal phase in the minerals category comes from recycling of metals which diminishes the environmental load.

To obtain more transparent results of the LCA, let us group the 11 impact categories into three *damage categories* considered in Eco-indicator 99:

- *Human health:* carcinogens, respiratory inorganics, respiratory organics, climate change, radiation, ozone layer. The unit DALY (Disability Adjusted Life Years), which is used in this damage category, expresses different disabilities caused by diseases as well as years lost in consequence.
- *Ecosystem quality:* ecotoxicity, acidification/eutrophication, land use. The unit PDF·m$^2$·year (Potentially Disappeared Fraction) stands for the loss of species – decreased biodiversity.

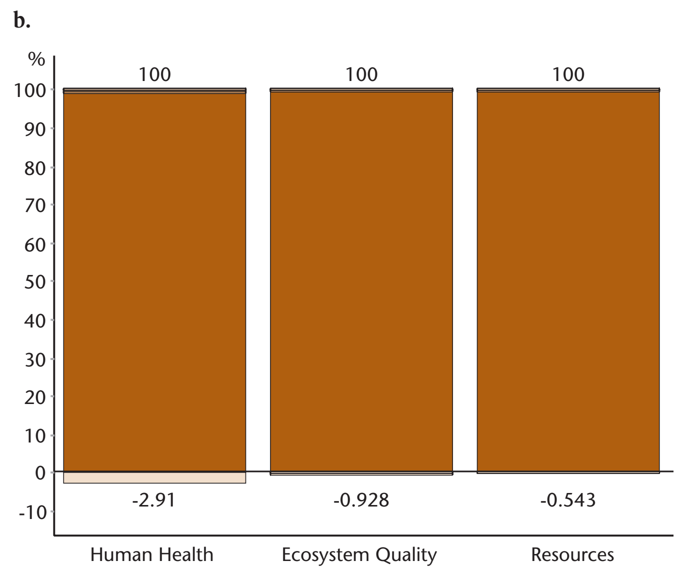



**Figure 9.5 Life cycle impact assessment of the aluminium frame window for each life cycle phase. a.** *The diagram shows the impact in 11 different impact categories calculated for one piece of window. The heights are 100% for the entire life cycle. The numerical values are percentage of total effect score in each impact category. impact factors.* **b.** *Impact for three damage categories. The numerical values are percentage of total effect score in each damage category. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

ALU window manufacturing | replacement of ferrules
dismantling ALU window | replacement of gaskets (ALU)

- *Resources:* minerals and fossil fuels. This damage is expressed in MJ surplus energy required for a future acquisition of minerals and fossil fuels.

Results of this aggregation are presented in Figure 9.5b. Analysis of Figure 9.5b confirms the conclusions from Figure 9.5a that the production phase causes the major environmental impact in the entire life cycle of the aluminium window.

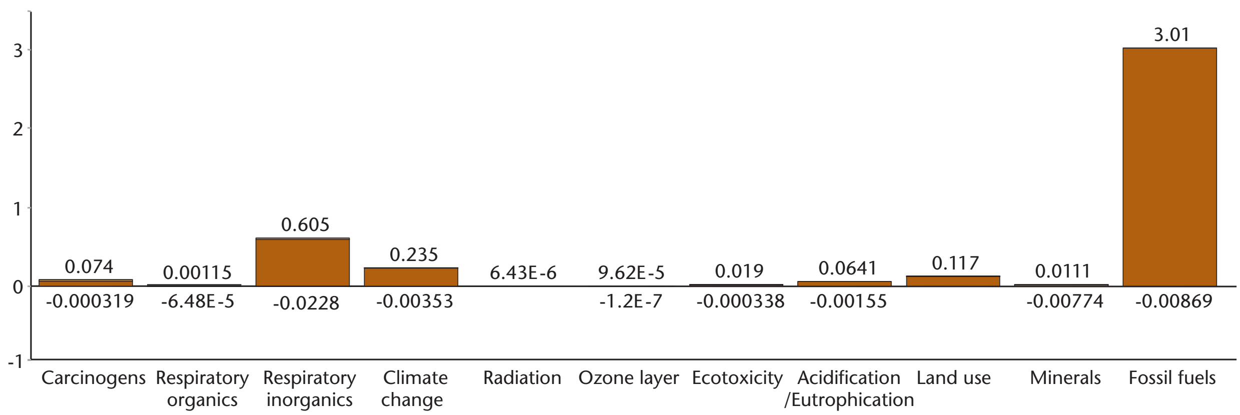
### 9.2.5 Normalisation

Normalisation is performed to make the effect scores of the environmental profile comparable. Normalised effect score is the ratio of an effect score for a given product annual contribution to that effect in a certain time over a certain area (compare for example Table 6.3 and Figure 6.3).

Eco-indicator 99 deals with normalisation by relating the environmental profile to the values representing the damage caused in the environment per inhabitant in given area (e.g. Europe), per year. To perform a normalisation process for all categories, all the impact must be multiplied by coefficients obtained from a statistical analysis of global emissions in a given area over the period of one year. For Eco-indicator 99 the impacts resulting in the deterioration of human health are multiplied by the factor of 65.1, in the deterioration of ecosystem quality by $1.95\ 10^{-4}$ and in the resources by $1.19\ 10^{-4}$. The only exception constitutes ecotoxicity whose single score is multiplied by 0.1 before it is normalised. A detailed description of the coefficients applied in the method used is given in Table 9.4a.

The results of normalisation in the 11 impact categories (Figure 9.6a) shows that the biggest environmental burden associated with the life cycle of an aluminium window per inhab-

**a.**




**a.**

| Impact category | Unit | Characterisation | | Normalisation |
|---|---|---|---|---|
| Carcinogens | DALY | 0.00113 | * 65.1 | 0.0737 |
| Resp. organics | DALY | 1.67E-5 | * 65.1 | 0.00109 |
| Resp. inorganics | DALY | 0.00895 | * 65.1 | 0.583 |
| Climate change | DALY | 0.00355 | * 65.1 | 0.231 |
| Radiation | DALY | 9.88E-8 | * 65.1 | 6.43E-6 |
| Ozone layer | DALY | 1.48E-6 | * 65.1 | 9.6E-5 |
| Ecotoxicity | PAF*m2yr | 958 | *0.1, * $1.95 \cdot 10^{-4}$ | 0.0187 |
| Acidification/ Eutrophication | PDF*m2yr | 321 | * $1.95 \cdot 10^{-4}$ | 0.0625 |
| Land use | PDF*m2yr | 598 | * $1.95 \cdot 10^{-4}$ | 0.117 |
| Minerals | MJ surplus | 28 | * $1.19 \cdot 10^{-4}$ | 0.00333 |
| Fossil fuels | MJ surplus | 2.53E4 | * $1.19 \cdot 10^{-4}$ | 3.01 |

**b.**

| Damage category | Unit | Characterisation | | Normalisation |
|---|---|---|---|---|
| Human Health | DALY | 0.0137 | * 65.1 | 0.889 |
| Ecosystem Quality | PDF*m2yr | 1.01E3 | * $1.95 \cdot 10^{-4}$ | 0.198 |
| Resources | MJ surplus | 2.53E4 | * $1.19 \cdot 10^{-4}$ | 3.01 |

**Table 9.4 Normalisation for the environmental impact of the aluminium frame window. a.** *Effect scores after characterisation, normalisation coefficients and normalised effect scores for eleven impact categories.* **b.** *Effect scores after characterisation, normalisation coefficients and normalised effect scores for three damage categories. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

**b.**

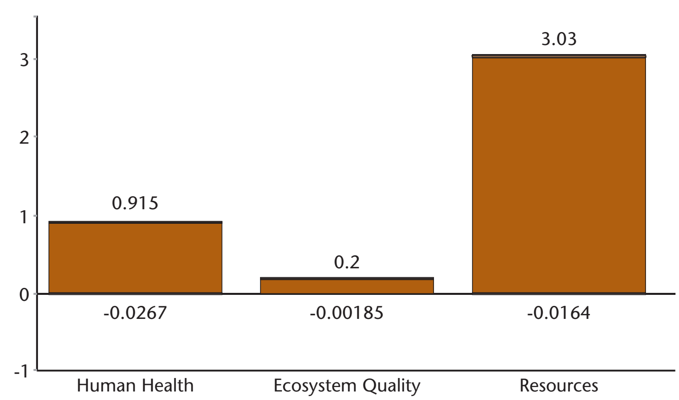



**Figure 9.6 Normalisation of the environmental impact of the aluminium frame window for each life cycle phase. a.** *Normalised effect scores for eleven impact categories divided into life cycle phases. Total values are found in Table 9.4a.* **b.** *Normalised effect scores for three damage categories divided into life cycle phases. Total values are found in Table 9.4b. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

ALU window manufacturing
replacement of ferrules
dismantling ALU window
replacement of gaskets (ALU)

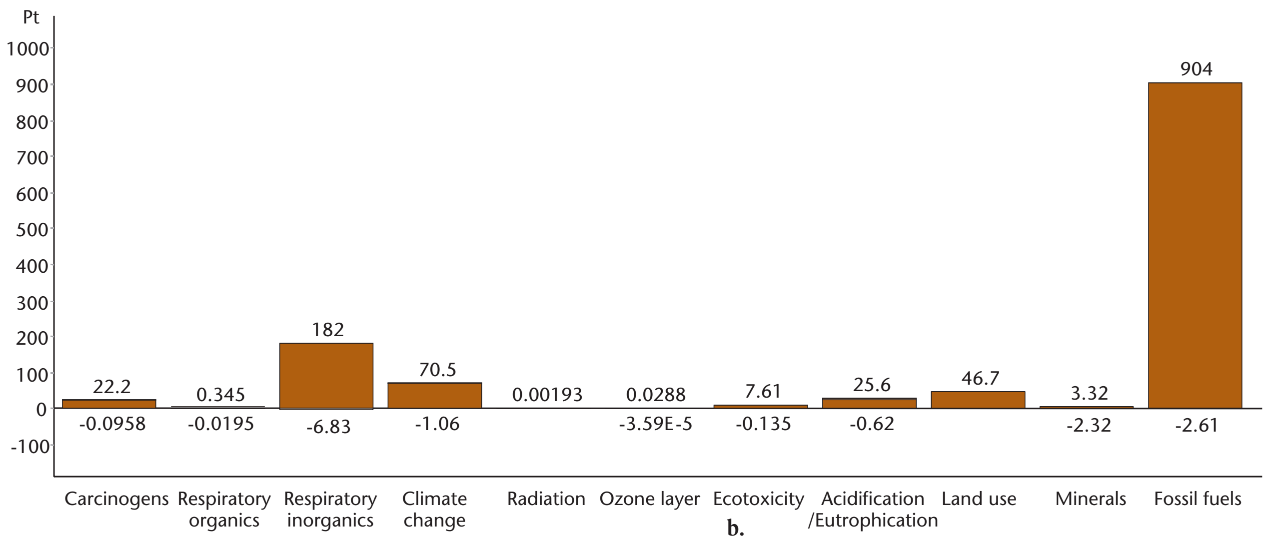
itant of Europe per year is attributed to the impact categories *fossil fuels* and *respiratory inorganic*. Similarly as in the characterisation phase, this result is ascribed to the production phase of an aluminium window (dark brown colour in Figure 9.6a).

The final results of the normalisation can also be expressed by aggregation of the impact categories into the three damage categories human health, ecosystem quality, and resources (Figure 9.6b).

Normalisation proved that the most important environmental impact in the life cycle of an aluminium window is the depletion of fossil fuels associated with aluminium extrusion. This has its greatest influence on the outcome for damage category *resources*. The next most important environmental impacts are from emissions of respiratory inorganic and greenhouse gases, both influencing human health.

Normalisation coefficients characteristic for selected damage categories are shown in Table 9.4b.

**a.**




**a.**

| Impact category | Normalisation | | Weighing |
|---|---|---|---|
| Carcinogens | 0.0737 | | 22.1 |
| Resp. organics | 0.00109 | | 0.326 |
| Resp. inorganics | 0.583 | * 300 | 175 |
| Climate change | 0.231 | | 69.4 |
| Radiation | 6.43E-6 | | 0.00193 |
| Ozone layer | 9.6E-5 | | 0.0288 |
| Ecotoxicity | 0.0187 | | 7.47 |
| Acidification/ Eutrophication | 0.0625 | * 400 | 25 |
| Land use | 0.117 | | 46.7 |
| Minerals | 0.00333 | * 300 | 0.999 |
| Fossil fuels | 3.01 | | 902 |

**b.**

| Damage category | Normalisation | | Weighting |
|---|---|---|---|
| Human Health | 0.889 | * 300 | 267 |
| Ecosystem Quality | 0.198 | * 400 | 79.1 |
| Resources | 3.01 | * 300 | 903 |

**Table 9.5 Weighting for the environmental impact of the aluminium frame window. a.** *Normalised effect scores, weighting coefficients and normalised and weighted effects scores, so-called eco-points for eleven impact categories.* **b.** *Normalised effect scores, weighting coefficients and normalised and weighted effects scores, so-called eco-points for three damage categories. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

**b.**

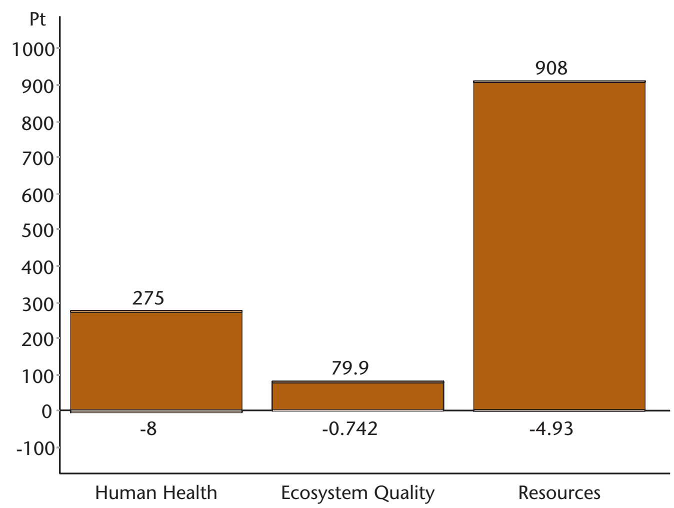



**Figure 9.7 Weighting of the environmental impact of the aluminium frame window for each life cycle phase. a.** *Normalised and weighted effect scores, so-called eco-points (Pt) for eleven impact categories divided into life cycle phases.* **b.** *Normalised and weighted effect scores, so-called eco-points (Pt) for three damage categories divided into life cycle phases. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

ALU window manufacturing
replacement of ferrules
dismantling ALU window
replacement of gaskets (ALU)

## 9.2.6 Weighting

Weighting is the step in which the different impacts categories are weighted for comparison between themselves, i.e. the relative importance of the effects is assessed. Weighting allows us to arrive at one single score representing the environmental impact of a product.

Like normalisation, the weighting process is performed on the damage assessment level by multiplying a normalised environmental profile by a set of weighting factors, which reflect the seriousness of a given effect (assessed by an expert panel, Box 6.1).

In Eco-indicator 99 the following *weighting factors* are attributed to the damage categories:

- Human health 300
- Ecosystem quality 400
- Resources 300

Selection of weighting factors in Eco-indicator 99, which is based on local preferences and social values, rates the ecosystem (400) higher than human health and resources, whose seriousness has been assessed to be equal (300). Multiplication of normalisation coefficients by weighting factors gives single scores for each category (Table 9.5a). The normalised and weighted effect score is called eco-points in the Eco-indicator 99 model and is expressed as points (Pt). A graphical representation of the result of the calculations is shown in Figure 9.7a.

Comparing the results of normalisation and weighting phases, we may conclude that the general outcome is similar. The most significant environmental burden is ascribed to impact categories *fossil fuels* and *respiratory inorganics* (caused by the manufacturing phase, dark brown colour for *ALU window*). The only difference between the normalisation and weighting phases is the proportion between the impacts. This difference is the result of the assumption of weighting coefficients which give priority to ecosystem quality over human health and resource depletion. Figure 9.7a also shows negative values of particular impacts. Negative values represent these inflows and outflows which are not released to the atmosphere due to recycling and energy recovery.

The results of the weighting phase can be also analysed for damage categories (Figure 9.7b). Weighting coefficients characteristic of selected damage categories and final results of weighting are shown in Table 9.5a. Weighting did not change significantly the proportions between damage categories. Nevertheless, resource depletion resulting from the production phase dominates.

## 9.2.7 Single Score

Eco-indicator 99 is one of the methods which allow us to arrive at one single score for the entire life cycle – a so-called *environmental index*, or environmental score, both expressions are used. This is the sum of all individual eco-points or partial indices for all life cycle processes. The computational procedure is performed by adding up the results of weighting within life cycle phases (production phase – *ALU window*, disposal phase – *dismantling ALU window* and use phase – *replacement of ferrules* and *replacement of gasket*). The results can

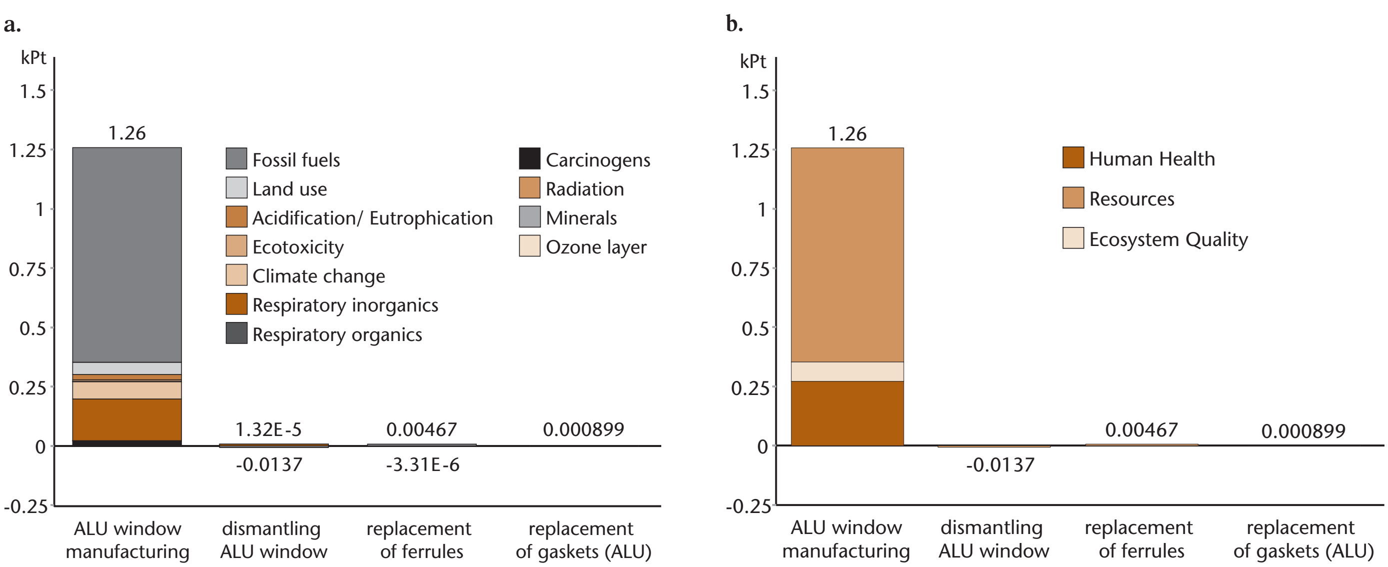



**Figure 9.8 Environmental scores (indices) for the life cycle of the aluminium frame window for four life cycle functions. a.** *The colour code shows 11 impact categories. Fossil fuel use is the dominating one.* **b.** *The colour code shows the three damage categories human health, resource use and ecosystem quality. The numerical values are total eco-points or indices for all partial process. The grand total for the aluminium frame window is 1260 eco-points, here expressed in thousand points (kPt). The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

be displayed for damage categories (Figure 9.8a) or for impact categories (Figure 9.8b). The environmental index is thus 1260 eco-points.

Almost 100% of the single score in case of an aluminium window is allocated over the production phase (ALU window). Manufacturing of an aluminium window affects mostly human health and resource depletion (Figure 9.8a). The negative values calculated for the final disposal comes from metals and glass recycling. The same analysis for impact categories shows the highest scores in *fossil fuels* and *respiratory inorganics* categories.

## 9.3 PVC Window LCA

### 9.3.1 Life Cycle Inventory

The LCA analysis for a PVC window was performed in identical way as for the ALU window. Illustration of the first step in the LCA, the Life Cycle Inventory for the PVC window (Figure 9.9) displays inflows and outflows for all life cycle phases of the PVC window.

As in the case of the ALU window, all the technical data were collected from companies installing windows in Lodz, Poland.

Basic technical data collected for the LCA analysis of the PVC window are displayed in Table 9.5b.

The total mass of the PVC window is 67.4 kg. Of this, 24.2 kg is the weight of the PVC profiles and other PVC ele-

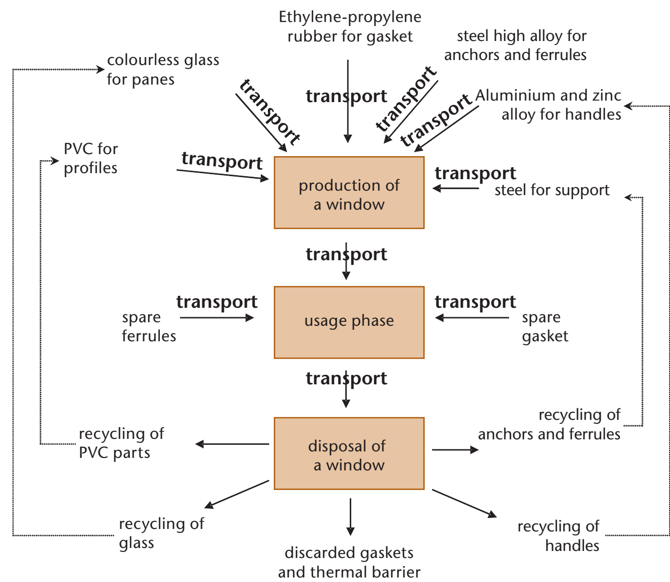



**Figure 9.9 Inventory of inflows and outflows**. *The inventory diagram for the life cycle of the PVC frame window.*

**Table 9.6 Technical data for LCA of the PVC window.** *Data shown for white PVC profile. The weight of other elements are estimated to be only few grams and is thus neglected. The weight of the support is estimated to be 0.85 kg/running meter. The weight of the gasket is estimated to be 0.015 kg/running meter. The glass is estimated to be 1 mm thick and have a total weight of 2.5 kg/m². The weight of the ferrule is estimated to be 2.5 kg and the anchors 0.25 kg.*

| White PVC profile | | | |
|---|---|---|---|
| Element | Length (m) | Mass of running meter (kg) | Mass of the element (kg) |
| Frame | 5.8 | 1.4 | 8.12 |
| Muntin | 1.4 | 1.68 | 2.352 |
| Sashes | 8.2 | 1.43 | 11.729 |
| Sash stop | 7.3 | 0.25 | 1.825 |
| Other elements (estimated) | | | ~ 0 |
| Total | | | 24.0 |

| Other elements and accessories | | | |
|---|---|---|---|
| Name | Material | Quantity | Mass (kg) |
| Support | Carbon steel S 10 | 14 m | 11.9 |
| Gasket | Ethylene-propylene rubber (EPDM) | ~ 16.4 m | 0.25 |
| Panes | Colourless glass | Two double integrated panes 4/16/4 of size 561x1241. | 27.8 |
| Ferrules and anchors | High-quality steel | 1 set | 2.75 |
| Handles | Aluminium and zinc alloy (ZnAl) | 1 set | 0.5 |
| Total | | | 43.2 |

ments. Main PVC profiles are imported from a factory near Berlin. The road distance is around 600 km. Particular elements are produced by extrusion.

Metal sections for supports are made of steel and have a total weight of 11.9 kg. They are transported from Katowice through Wrocław, a distance of 400 km.

Ferrules, made of high quality steel, weigh 2.75 kg. They are imported from Austria via Czekanów (600 km).

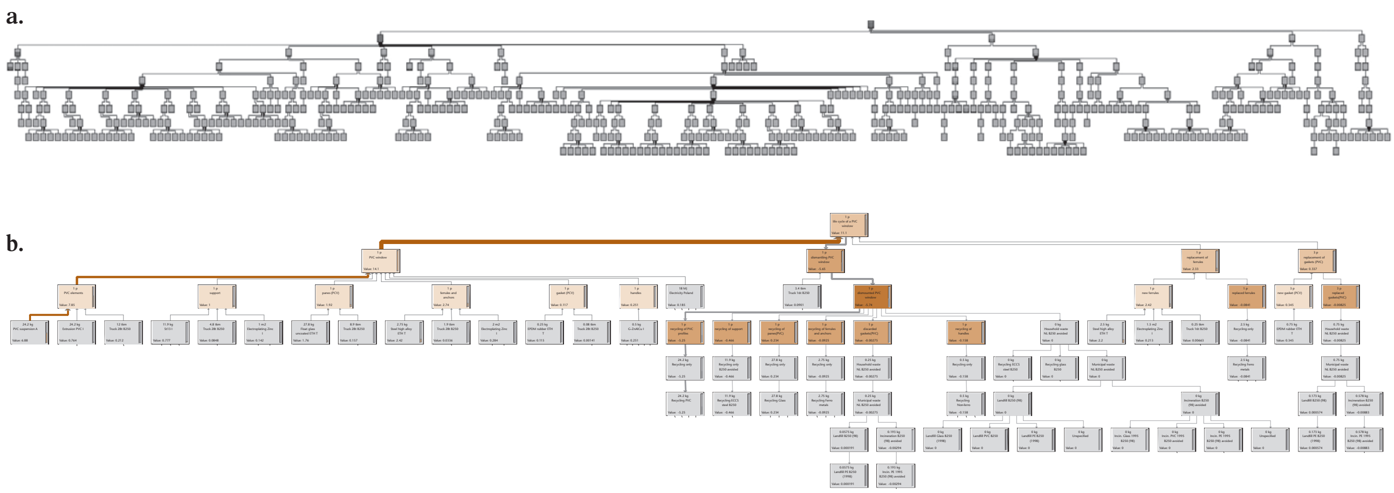
The glass, with a total weigh of 27.8 kg, is the *float* type produced in Sandomierz (Poland). It is integrated hermetically into window panes in Czestochowa (distance 320 km).

Other material includes the handles made of zinc aluminium alloy (0.5 kg) and some plastics.

During 40-year use the window requires one replacement of ferrules (after around 20 years) and three replacements of gaskets (every 10 years). These elements have their own life cycles. The replaced ferrules are scrapped and gaskets are discarded. After 40 years, a window is dismounted. Plastic elements, supports, handles, ferrules, anchors and panes can be recycled. The rest, i.e. gaskets, are discarded, partly incinerated and partly land filled (according to a Dutch scenario of municipal waste utilisation). Instead of dividing the transport according to particular groups of objects, it was assumed that the whole window is transported a distance of 50 km.

Due to the lack of sufficient data, the following effects have been neglected:

- Window cleaning.
- Elements necessary for glass integration (small amounts of butyl, thioplast and aluminium frames).



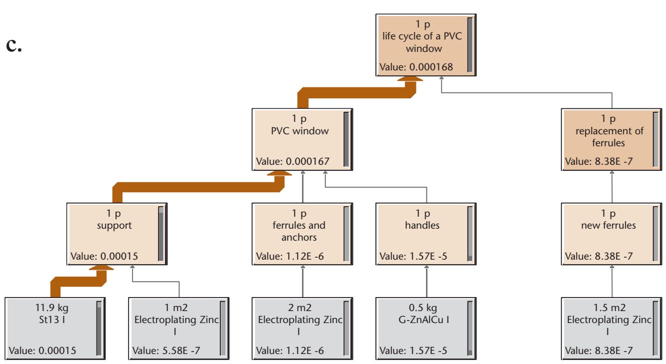




**Figure 9.10 Process trees for and LCA of the PVC frame window. a.** *Full process tree for a life cycle of the PVC frame window generated by SimaPro.* **b.** *Simplified process tree in which several processes are grouped into one box. This includes environmental indices calculated according to Eco-indicator 99. The thickness of the lines is proportional to the environmental impact.* **c.** *Simplified process tree in which only elements with an environmental index larger that 0.1% for the impact category VOC emissions is included.*

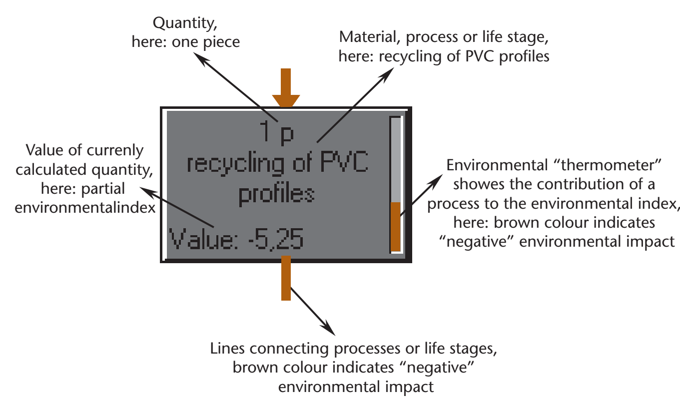



**Figure 9.11 A process box for the calculation of an environmental index.** *The calculation is made for an item in the life cycle of the PVC frame window. The process box contains the life stage, the material, the quantity, the environmental index for that impact, and the thermometer showing the contribution of the process to the total environmental index.*

### 9.3.2 Process Trees

The full process tree for the PVC window, developed by the software SimaPro, is shown in Figure 9.10a. The grey boxes in the figure schematically represent subsequent technological processes grouped into life phases (production, usage, disposal). The figure shows that the life cycle of a PVC window is as complex as that of an aluminium window (Figure 9.3a).

As in the previous analysis, certain inflows and outflows were grouped in only one box. An example of a simplified process tree for the PVC window (Figure 9.10b) shows environmental indexes of the life cycle phases calculated according to the Eco-indicator 99 method. The thickness of lines graphically illustrates the level of environmental impact of particular processes constituting a life cycle of the PVC window.

A process box for calculation of environmental index is shown in Figure 9.11. Negative values in the box result from emissions avoided due to recycling or energy recovery.

The process tree shown in Figure 9.10b can be further simplified to exclude the weak influence of certain processes in the life cycle, for example, if considering volatile organic compounds (VOC) emissions, after omitting components that contribute less than 0.1% of all VOC emissions (Figure 9.10c).

The values in the boxes of the process tree represent the mass emitted in the different technological process expressed in kilos. Nearly 90% of the VOC emissions in the life cycle of a plastic window come from the manufacturing of the steel sections which are used as the window profile support. It is worth noting that unwanted emissions of VOC are not connected with the production of steel itself but with the transportation of steel by bulk carriers which run on heavy fuel oil.

Similar modifications of the process tree can be obtained by setting up different cut-off rules.

For the PVC window the full inventory table consists of 588 items. A huge number of inflows and outflows thus occur during the PVC window life cycle. Collection and data quality assessment are the first and crucial steps to develop reliable LCA for any products or systems. Selected items of an inventory table for the life cycle of the PVC frame window are shown in Table 9.7.

**Table 9.7 Inventory table for the life cycle of the PVC frame window.** *The table is generated by the SimaPro software and its database and contains 588 entries.*

| No | Substance | Comp△ | Unit | Total | PVC window | dismantling PVC | replacement of f | replacement of g |
|---|---|---|---|---|---|---|---|---|
| 1 | acids | Raw | g | 14,9 | x | 14,9 | x | x |
| 2 | additions | Raw | g | -47,5 | x | -47,5 | x | x |
| 3 | additives | Raw | g | -355 | x | -355 | x | x |
| 4 | air | Raw | oz | 181 | 186 | -2,76 | -2,51 | x |
| 5 | alloys | Raw | g | 6,19 | x | 6,19 | x | x |
| 6 | auxiliary materials | Raw | g | 137 | x | 137 | x | x |
| ⋮ | | | | | | | | |
| 8 | baryte | Raw | g | 66,1 | 30,5 | 21,2 | 9,13 | 5,3 |
| 9 | bauxite | Raw | oz | 91,1 | 48,2 | 1,24 | 41,6 | 0,0224 |
| 10 | bentonite | Raw | g | 86 | 35,4 | 22,4 | 27,5 | 0,715 |
| ⋮ | | | | | | | | |
| 141 | CFC-114 | Air | mg | 2,12 | 1,22 | x | 0,708 | 0,193 |
| 142 | CFC-116 | Air | mg | 29,3 | 14,8 | 1,67 | 12,9 | 0,0069 |
| 143 | CFC-12 | Air | µg | 17,3 | 9,94 | x | 5,78 | 1,58 |
| 144 | CFC-13 | Air | µg | 10,9 | 6,24 | x | 3,62 | 0,99 |
| 145 | CFC-14 | Air | mg | 262 | 133 | 13,3 | 116 | 0,0621 |
| ⋮ | | | | | | | | |
| 277 | Cl- | Water | oz | 209 | 229 | -25,3 | 3,73 | 1,26 |
| 278 | Cl2 | Water | mg | 42,3 | 42,3 | x | x | x |
| 279 | Co | Water | mg | 110 | 43,2 | 45,1 | 20,9 | 0,877 |
| 280 | COD | Water | g | -2,36 | 20 | -23,2 | 0,388 | 0,497 |
| 281 | Cr | Water | g | 2,28 | 1,48 | 0,0617 | 0,736 | 0,00352 |
| 282 | Cr (VI) | Water | µg | 109 | 33,2 | 59,1 | 16,1 | 0,892 |
| ⋮ | | | | | | | | |
| 398 | slag | Solid | oz | -126 | 0,0457 | -127 | 0,000143 | x |
| 399 | slags/ash | Solid | oz | -27,2 | 8,9 | -36,1 | x | x |
| 400 | steel scrap | Solid | g | 263 | x | 138 | 125 | x |
| 401 | tinder from rolling drum | Solid | g | -109 | x | -109 | x | x |
| 402 | unspecified | Solid | mg | 213 | 213 | x | x | x |
| 403 | waste bioactive landfill | Solid | kg | 0 | x | 0 | x | x |
| ⋮ | | | | | | | | |
| 585 | Zn65 to air | Non mat. | µBq | 455 | 262 | x | 152 | 41,5 |
| 586 | Zn65 to water | Non mat. | mBq | 84,2 | 48,9 | x | 27,8 | 7,57 |
| 587 | Zr95 to air | Non mat. | µBq | 6,8 | 3,91 | x | 2,27 | 0,62 |
| 588 | Zr95 to water | Non mat. | mBq | 527 | 303 | x | 176 | 47,9 |

### 9.3.3 Characterisation

The characterisation phase for the PVC window was performed in an identical way as for the aluminium window, including computational procedures used for aggregating the data and by application of identical equivalence factors (Table 6.2).

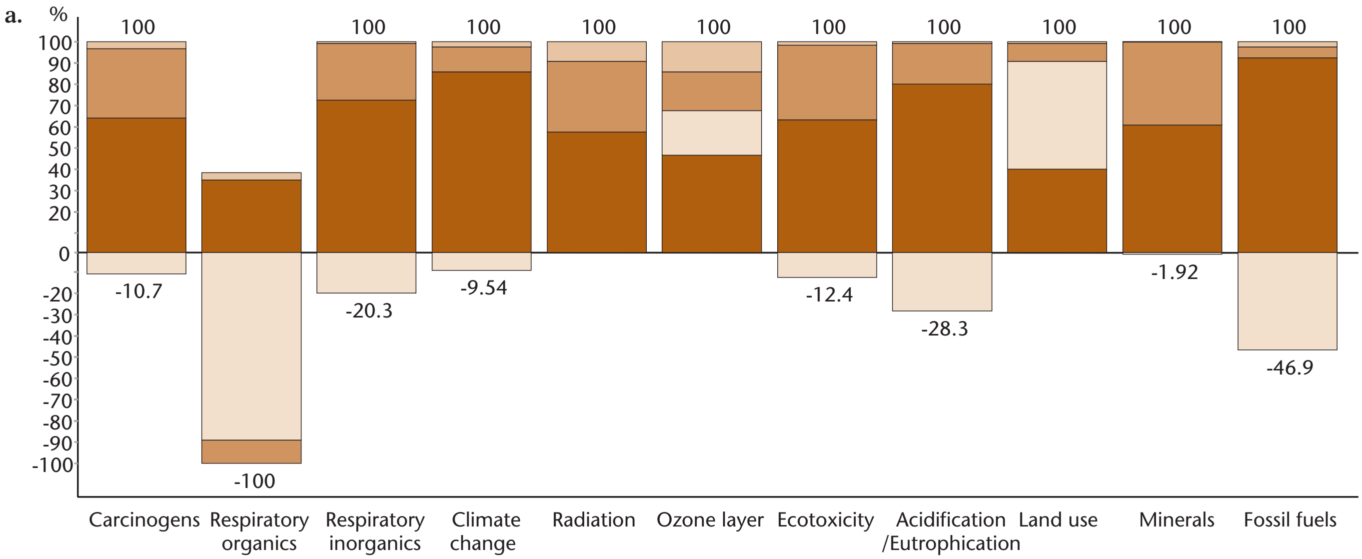
The results of a characterisation phase are absolute values of impacts expressed in effect scores or indices (not shown, but compare Table 9.3). The relative values in percentage for the total for each life cycle phase for the eleven impact and three damage categories are graphically presented in Figure 9.12.

The analysis shows that the manufacturing phase of the PVC window produces the biggest impact in the life cycle of the window (dark brown colour), although this effect is not as significant as in the case of the aluminium window (compare Figure 9.5). The use phase (especially replacement of ferrules and window dismantling) covers a substantial part of the environmental load in several impact categories. In the impact categories r*espiratory organics* and *fossil*, high negative values in the disposal phase are due to efficient technology of PVC recycling.

Deeper analysis of an inventory table for the PVC window indicates that the following substances have the most significant contributions for each impact category:

*Carcinogens:* These include mainly nickel, arsenic and cadmium emitted to water and air. They are involved in the production of steel for ferrules and profile supports as well as glass. During the utilisation phase, the highest negative values are recorded, from recycling handles and supports, and the positive ones – from producing electricity necessary for PVC and glass recycling. However, the final result for *dismounting* is negative.

*Respiratory organics:* Emissions of volatile organic substances (excluding methane) and ethylene accompany mainly PVC production and extrusion. However, negative emissions of hydrocarbons of general formula $C_XH_Y$ obtained by recycling of PVC and ferrules, prevail.




*Respiratory inorganics:* These are primarily emissions of sulphur and nitric oxides related mainly to the production of steel and PVC, and also negative emissions of dust during PVC recycling.

*Climate change:* Over 90% of results in this category include $CO_2$ emissions generated during the production of electricity necessary for recycling and for the production of PVC by the suspension technique, and the production of steel for ferrules and of glass. Negative emissions for the terminal phase of the life cycle are a result of window profile supports recycling.

*Radiation:* The greatest contributions are from the processes of production of steel for ferrules, glass, and synthetic rubber for gaskets. For the production stage the result is represented by a total contribution of these processes, while in the replacement of ferrules and gaskets it is multiplied (multiple replacement).

*Ozone layer:* HALON 1301 ($CF_3Br$) emitted during steel and gasket production is almost entirely responsible for the result in this category. Dismantling of a window has a positive contribution in this category because of the production of electricity needed for recycling.

*Ecotoxicity:* The most important substances toxic for the environment in the life cycle of a plastic window are nickel, zinc, and copper, as well as other emissions to the atmosphere. The emissions are induced by the production of steel for ferrules. Negative emissions are related to the recycling of handles and panes (negative lead and cadmium emissions).

*Acidification/eutrophication:* Noteworthy in this category are emissions of nitric oxides and sulphur dioxide connected with the production of steel for ferrules, PVC and electricity. The negative result for the phase of window utilisation was obtained by the recycling of plastic profiles and supports.

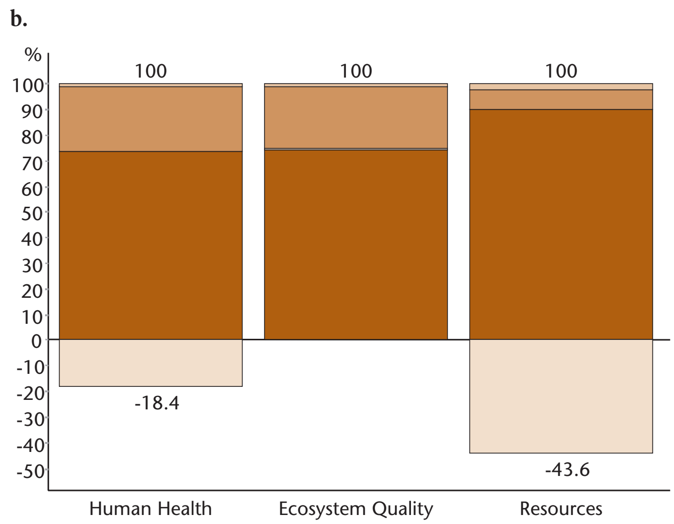



**Figure 9.12 Life cycle impact assessment of the PVC frame window for each life cycle phase. a.** *The diagram shows the impact in 11 different impact categories calculated for one piece of window. The heights are 100% for the entire life cycle. The numerical values are percentages of total effect score in each impact category.* **b.** *Impact for three damage categories. The numerical values are percentages of total effect score in each damage category. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

PVC window manufacturing | replacement of ferrules
dismantling PVC window | replacement of gaskets (PVC)

*Land use:* The greatest impact on the environment has the production of electric energy for recycling and transport of steel by bulk cargo ships.

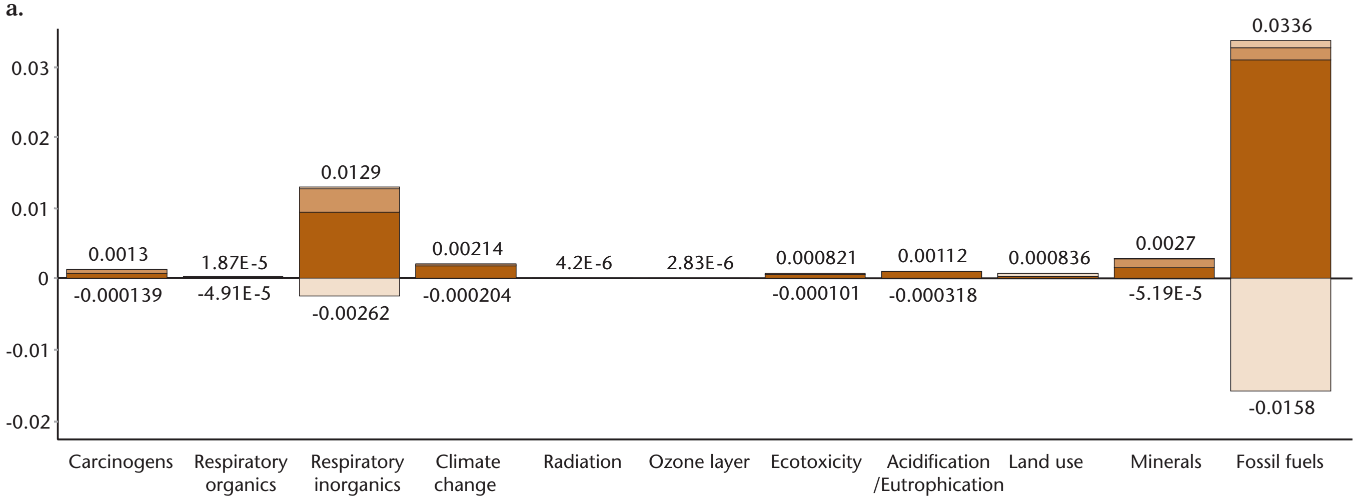
*Minerals:* The consumption of minerals depends greatly on the production of high-quality steel for ferrules and anchors (mainly nickel and zinc). Recycling of metal parts makes it possible to avoid mining of iron and zinc ores.

*Fossil fuels:* In the phase of production, the most crude oil and natural gas is used. Processes that are most important include the production of PVC and electric energy. The negative fuel consumption which occurs in the phase of window dismantling is a result of PVC recycling.

As before the results can be aggregated into three damage categories; human health, ecosystem quality and depletion of natural resources. Carcinogens, compounds that cause respiratory diseases, greenhouse effect, radiation, and depletion of ozone layer contribute to the deterioration of human health. Compounds toxic to the environment, eutrophication, acidification and extension of areas occupied by man deteriorate the conditions of life of many species on Earth (ecosystem quality), while consumption of minerals and fossil fuels reflects depletion of natural resources. From the figure it follows that for each end point, the most harmful stage in PVC window life cycle is the production phase (dark brown colour, Figure 9.12b).

Analysing the results in damage categories, we may also conclude that by recycling of PVC, the impact of the window life cycle on human health, and resource depletion are substantially reduced (see negative values in Figure 9.12b, dismantling of PVC window).

**a.**




**a.**

| Impact category | Unit | Characterisation | | Normalisation |
|---|---|---|---|---|
| Carcinogens | DALY | 1.78E-5 | * 65.1 | 0.00116 |
| Resp. organics | DALY | -4.68E-7 | | -3.04E-5 |
| Resp. inorganics | DALY | 0.000157 | | 0.0102 |
| Climate change | DALY | 2.98E-5 | | 0.00194 |
| Radiation | DALY | 6.45E-8 | | 4.2E-6 |
| Ozone layer | DALY | 4.34E-8 | | 2.83E-6 |
| Ecotoxicity | PAF*m2yr | 36.9 | *0.1 | 0.00072 |
| Acidification/ Eutrophication | PDF*m2yr | 4.13 | $*1.95 \cdot 10^{-4}$ | 0.000805 |
| Land use | PDF*m2yr | 4.29 | | 0.000836 |
| Minerals | MJ surplus | 22.3 | $*1.19 \cdot 10^{-4}$ | 0.00265 |
| Fossil fuels | MJ surplus | 150 | | 0.0178 |

**b.**

| Damage category | Unit | Characterisation | | Normalisation |
|---|---|---|---|---|
| Human Health | DALY | 0.000205 | * 65.1 | 0.0133 |
| Ecosystem Quality | PDF*m2yr | 12.1 | $*1.95 \cdot 10^{-4}$ | 0.00236 |
| Resources | MJ surplus | 172 | $*1.19 \cdot 10^{-4}$ | 0.0205 |

**Table 9.8 Normalisation for the environmental impact of the PVC frame window. a.** *Effect scores after characterisation, normalisation coefficients and normalised effect scores for eleven impact categories.* **b.** *Effect scores after characterisation, normalisation coefficients and normalised effect scores for three damage categories. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

**b.**

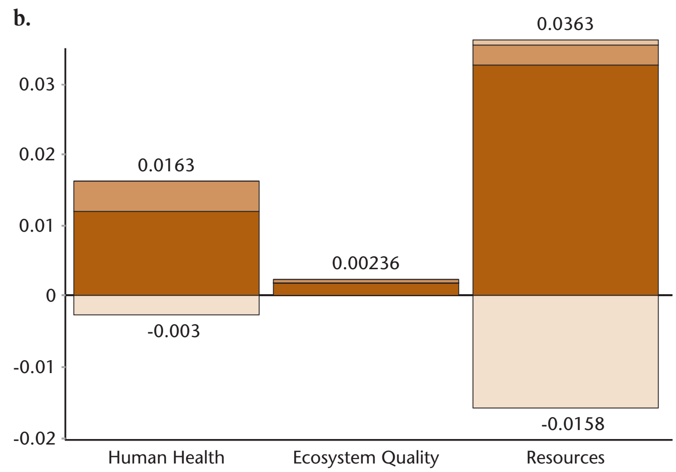



**Figure 9.13 Normalisation of the environmental impact of the PVC frame window for each life cycle phase. a.** *Normalised effect scores for eleven impact categories divided into life cycle phases. Total values are found in Table 9.8a.* **b.** *Normalised effect scores for three damage categories divided into life cycle phases. Total values are found in Table 9.8b. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

PVC window manufacturing
replacement of ferrules
dismantling PVC window
replacement of gaskets (PVC)

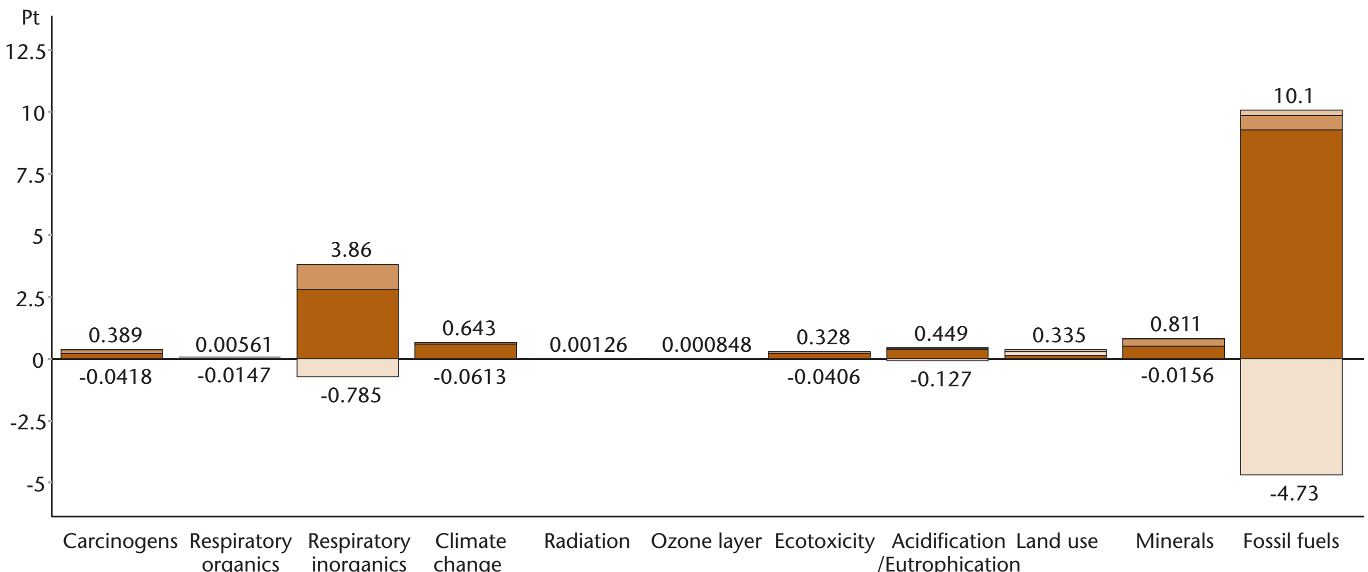
## 9.3.4 Normalisation

To make the environmental profiles comparable, the results achieved in characterisation phase must be normalised. The results of the characterisation are then multiplied by values reflecting the damage caused in the environment per inhabitant (e.g. of Europe), per year (Table 6.1).

Results of normalisation of PVC window life cycle are presented in Figure 9.13a. The calculations of the normalisation parameters are shown in Table 9.8a (according to Eco-indicator 99 methodology; for details, see previous section).

As can be easily seen, the life cycle of the plastic window contributes mostly to the depletion of fossil fuels (for the production of the PVC suspension) and emissions of respiratory inorganic compounds such as $SO_x$ or $NO_x$ (production of steel high alloy). Figure 9.8b shows the results of normalisation on the midpoints level, i.e. in impact categories. As in the LCA

**a.**




**a.**

| Impact category | Normalisation | | Weighing |
|---|---|---|---|
| Carcinogens | 0.00116 | * 300 | 0.347 |
| Resp. organics | -3.04E-5 | | -0.00913 |
| Resp. inorganics | 0.0102 | | 3.07 |
| Climate change | 0.00194 | | 0.581 |
| Radiation | 4.2E-6 | | 0.00126 |
| Ozone layer | 2.83E-6 | | 0.000848 |
| Ecotoxicity | 0.00072 | * 400 | 0.288 |
| Acidification/ Eutrophication | 0.000805 | | 0.322 |
| Land use | 0.000836 | | 0.335 |
| Minerals | 0.00265 | * 300 | 0.796 |
| Fossil fuels | 0.0178 | | 5.35 |

**b.**

| Damage category | Normalisation | | Weighting |
|---|---|---|---|
| Human Health | 0.0133 | * 300 | 4 |
| Ecosystem Quality | 0.00236 | * 400 | 0.944 |
| Resources | 0.0205 | * 300 | 6.15 |

**Table 9.9 Weighting for the environmental impact of the PVC frame window. a.** *Normalised effect scores, weighting coefficients and normalised and weighted effects scores, so-called eco-points for eleven impact categories.* **b.** *Normalised effect scores, weighting coefficients and normalised and weighted effects scores, so-called eco-points for three damage categories. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

**b.**

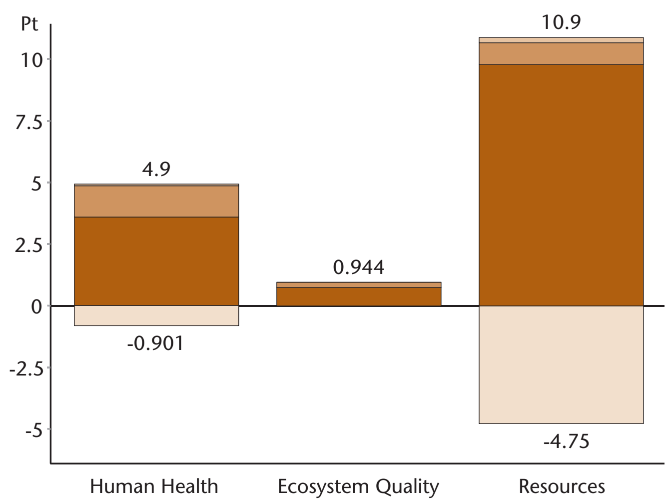



**Figure 9.14 Weighting of the environmental impact of the PVC frame window for each life cycle phase. a.** *Normalised and weighted effect scores, so-called eco-points (Pt) for eleven impact categories divided into life cycle phases.* **b.** *Normalised and weighted effect scores, so-called eco-points (Pt) for three damage categories divided into life cycle phases. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

PVC window manufacturing | replacement of ferrules
dismantling PVC window | replacement of gaskets (PVC)

of the ALU window, the final results of the normalisation can be also be expressed in damage categories by aggregation of impact categories into three groups: human health, ecosystem quality, and resources (Figure 9.13b). The procedures used to determine normalisation values in damage categories are shown in Table 9.8b.

Figure 9.13b and Table 9.8b show that the life cycle of the PVC window contributes strongly to the depletion of raw materials and to deterioration of human health. The influence of the plastic window life cycle on the deterioration of ecosystem quality is almost 10 times less than on resource depletion (Table 9.8b, last column).

### 9.3.5 Weighting

In the weighting step, different impacts and damage categories are weighed to be compared among themselves, i.e. to asses the relative importance of the effects and finally to obtain one single score representing the environmental impact of the product.

Weighting factors, which reflect the seriousness of a given effect selected according to Eco-indicator 99 methodology are identical for the LCA and ALU windows:

- Human health 300
- Ecosystem quality 400
- Resources 300

Results of this step of the LCA analysis are shown in Figure 9.14a and in Table 9.9a The results of normalisation and weighting phases are similar, i.e. the most serious environmental burden is ascribed to impact categories *fossil fuels* and *respiratory inorganics* (5.35 and 3.07 respectively, Table 9.9a) caused by the production phase (dark brown colour). The difference between the normalisation and weighting phases is the proportion between the impacts, due to the priority of ecosystem quality over human health and resources depletion. Negative values in Figure 9.14a and Table 9.9a represent inflows and outflows which are not released to the atmosphere due to recycling and energy recovery.

The results of the weighting phase were also calculated for damage categories (Figure 9.14b). Weighting coefficients characteristic for the three damage categories and final results of weighting are shown in Table 9.9b. The results of weighting did not change the normalisation results appreciably. However, the ratio between deterioration of ecosystem quality and resource depletion is equal now, about 7 (6.15/0.944, Table 9.9b, last column) while in the normalisation phase it was about 10. This result comes from the assumption of priority of ecosystem quality (400) over human health (300) and resources depletion (300), (Table 9.9b).

### 9.3.6 Single Score

Eco-indicator 99 allows us as before to obtain an *environmental index*, for the entire life cycle of products or services for damage categories (Figure 9.15a) or for impact categories (Figure 9.15b). The environmental index is calculated by summing up

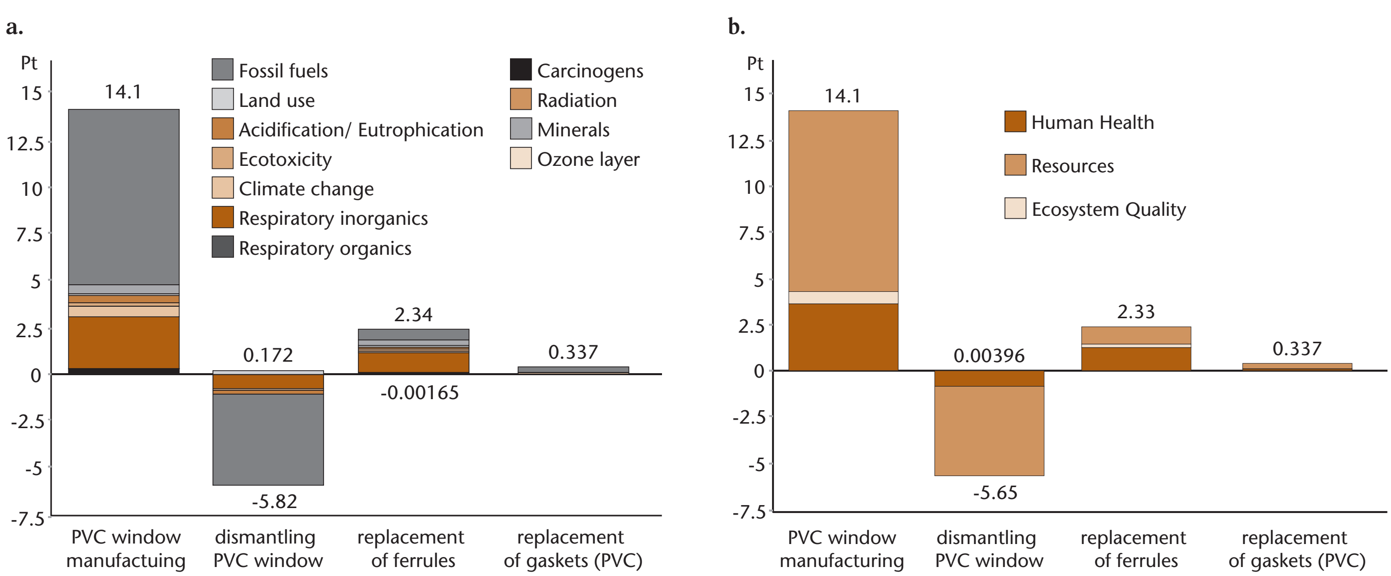
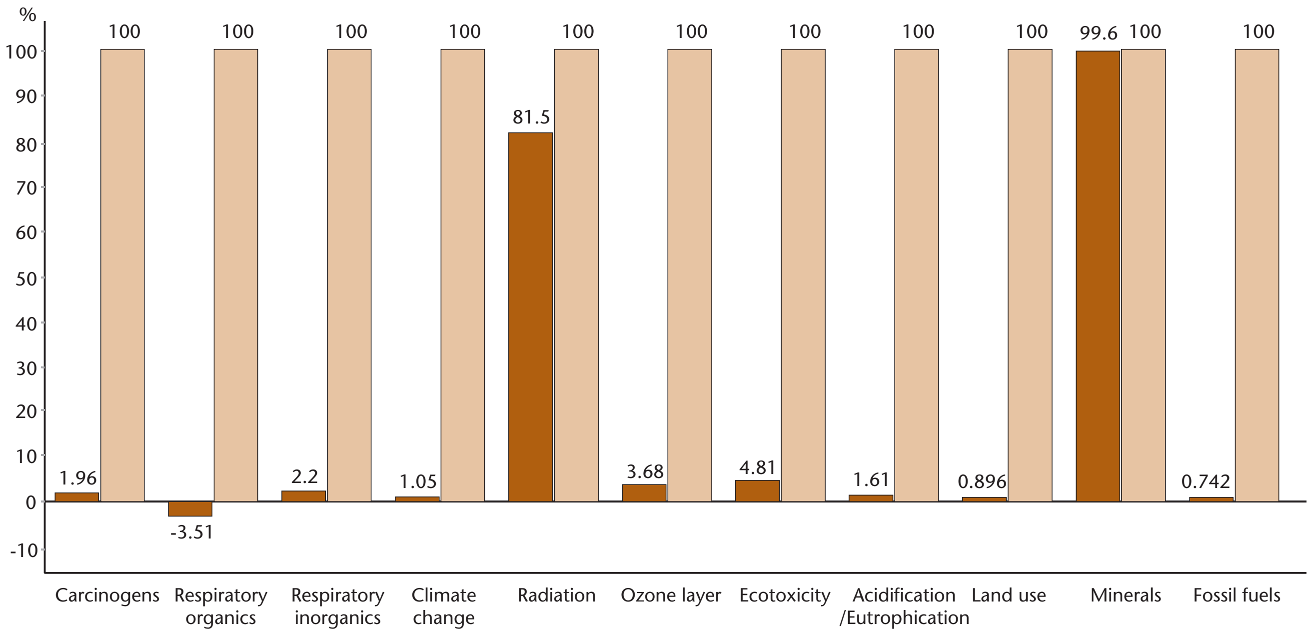



**Figure 9.15 Environmental scores (indices) for the life cycle of the PVC frame window for four life cycle functions. a.** *The colour code shows 11 impact categories. Fossil fuel use is the dominating one.* **b.** *The colour code shows the three damage categories human health, resource use and ecosystem quality. The numerical values are total eco-points or indices for all partial process. The grand total for the PVC frame window is 11.1 eco-points, expressed in points (Pt). The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

a.




b.

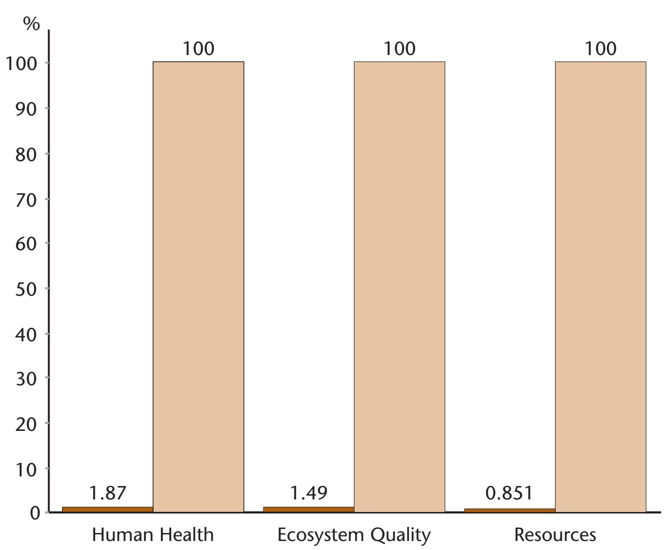



**Figure 9.16 Comparative analysis of the Aluminium and PVC frame windows – characterisation.** *The LCA of the two windows are compared for* **a)** *each of 11 different categories of impact and for* **b)** *each of three different damage categories. The largest effect score (index) for each pair was set to 100%. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

life cycle of a PVC window   life cycle of a aluminium window

respective values of partial environmental indices for product life cycle phases obtained after normalisation and weighting. The index adds up to 11.1 eco-points.

Figure 9.15a shows the environmental index for the PVC window, divided into lifetime stages and damage categories. The environmental index for the production phase of the PVC window is equal to 14.1 Pt. 10 Pt result from resource depletion, which means that main environmental load is located in the "resources" damage category. On the other hand, the PVC window utilisation phase is environmentally sound (environmental index equal to –5.65), which is due to recycling of PVC, metals and glass.

As a last step of the LCA of the PVC window, let us examine the partial environmental indices for the impact categories which provide more detailed information about the processes in the product life cycle (Figure 9.15b). As has been demonstrated before, the biggest environmental load associated with the PVC window is allocated to the *resources* and *human health* damage categories. Figure 9.15b shows that for damage category *resources* the biggest contribution comes from the *fossil fuels* impact category. This is due to the combustion of crude oil and natural gas used in PVC production and energy generation.

A comparison of Figures 9.15a and 9.15b shows that emissions of *respiratory inorganic* compounds place the biggest input in the damage category *human health* (dark brown colour in Figure 9.15a). This is caused by emissions of sulphur dioxide and nitric oxides during the production of PVC profiles and steel for ferrules.

## 9.4 Comparing Life Cycle Assessments of PVC and Aluminium Windows

### 9.4.1 Objective

Two environmental impacts of the life cycles of the PVC and aluminium windows were compared in a so-called comparative LCA analysis. The analysis was carried out using the same methods as used for the individual windows. As mentioned already, the lifetime of the PVC window was assumed to be 40 years and that of the aluminium window 50 years. Thus one aluminium window has to be compared to 1.25 PVC window. Selected results of the analysis are described below.

### 9.4.2 Characterization

Figure 9.16a shows the outcome of the characterisation phase in the comparative analysis of the windows. According to the standard for reporting this kind of analyses, the predominant effect for each impact category is set as the point of reference and is assumed to be equal to 100%. Figure 9.16a shows that an aluminium window has a bigger environmental impact in each impact category. This is mostly due to the energy intensive process of extrusion of aluminium profiles. However, for the categories *radiation* and *consumption of minerals* the environmental impacts of both products are comparable. For the impact category *radiation*, the major contribution is caused by manufacturing of steel for ferrules, glass and EPDM rubber. The small difference between environmental impacts in this category results mainly from the longer life cycle of the aluminium window.

For the impact category *minerals consumption* both windows cause almost the same environmental impact (99.6 and 100 respectively, Figure 9.16a). In this category, however, the aluminium consumption in manufacturing of a window is not taken into account since aluminium is almost 100% recycled, and can be used in another production process without causing any environmental impact. In consequence the main contribution in this category is allocated to steel production for ferrules and anchors, which is the same for both aluminium and plastic windows.

Figure 9.16b shows the results of characterisation of the PVC and aluminium windows life cycles for damage categories. After aggregation of all impact categories into the three damage categories, the conclusions are similar in terms of impact categories, i.e. the PVC window has a better environmental profile. After this step of comparative analysis there is no doubt that the PVC window is, environmentally speaking, the better product.

### 9.4.3 Normalisation

Figure 9.17a shows the results of normalisation carried out using the Eco-indicator 99 method. Here we see the proportions between environmental impacts produced by the two windows during their life cycles. The normalisation step did not change any conclusions about the superiority of the PVC over the aluminium window in terms of environmental impact.

### 9.4.4 Weighting

The results of weighting carried out by the Eco-indicator 99 method is reported in Figure 9.17b. Despite the preferences set to ecosystem quality (weighting factor 400), human health and resources (300), *resource* depletion resulting from the production phase of the windows causes the dominating environmental effects.

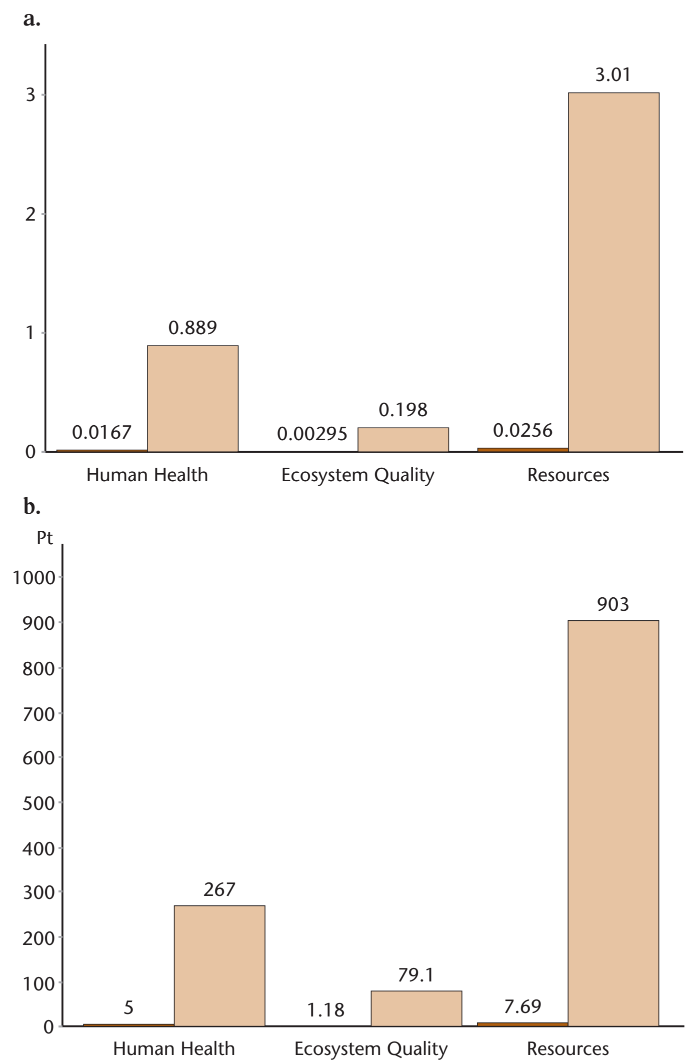



**Figure 9.17 Comparative analysis of the Aluminium and PVC frame windows – normalisation and weighting for each of three different damage categories. a.** *Normalised scores for the LCA of the two windows.* **b.** *The normalised and weighted scores for the two windows. The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

life cycle of a PVC window    life cycle of a aluminium window

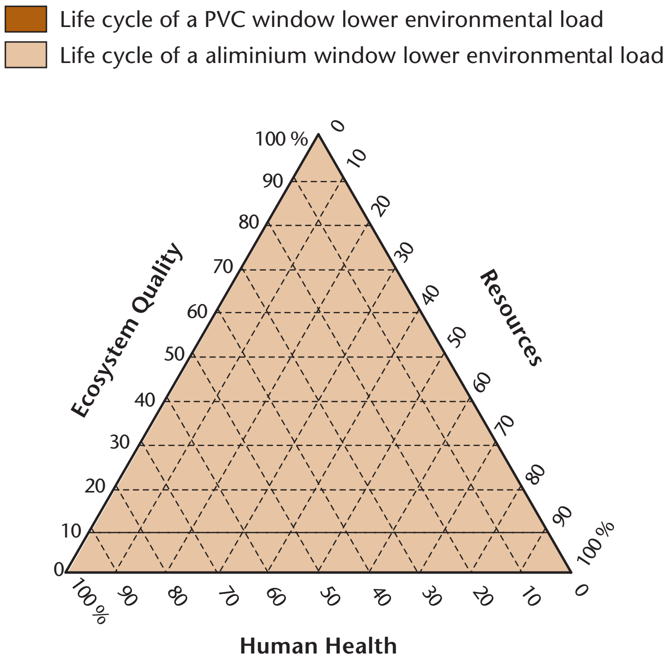



**Figure 9.18 Weighting triangle of the comparison of the LCA of Aluminium and PVC frame windows.** *The triangle shows how the weighting factors selected for the three impact categories influences the results. Here it is clear that the aluminium frame window contributes more than 99% of the environmental load of the two windows regardless of choice of weighting factors (compare for example Figures 6.8 and 6.9).*

The weighting phase in any LCA remains the most doubtful and controversial analysis because of the subjective assessment of environmental issues. One of the possibilities of illustrating the results of the weighting phase, if three damage categories are distinguished, is to use a *weighting triangle* [Goedkoop and Oele, 2001]. A weighting triangle indicates to what extent the result of an analysis is dependent on weighting factors.

The comparative analysis of the windows life cycles carried out with the aid of the weighting triangle shows that the results of the weighting phase are independent of the applied set of weighting factors, and that the plastic window is always superior over the aluminium window in environmental terms (Figure 9.18). The whole area of the weighting triangle is light brown which indicates that the life cycle of PVC window causes a lower environmental load for the whole range of weighting factors (i.e. for priority levels from 0-100%), for each damage category.

### 9.4.5 Process Contribution Analysis

*Process contribution analysis* is used to determine which processes in the life cycle of a product are most important, and to calculate their respective contributions in the environmental index. This information allows us to significantly simplify a process tree and focus our attention on the most important components and processes in the life cycle.

A process contribution analysis for the life cycles of both windows is given in Table 9.10. The table lists the contributions in percent of each process to the overall environmental index of the windows. For the aluminium window the extrusion and extraction of crude oil (50%) and other use of fossils definitely dominate the environmental profile. In the life cycle of the

**Table 9.10. Process contribution analysis for the Aluminium and PVC frame windows.** *Selected relative contributions (percentage) to environmental load of major processes in the life cycles of the two windows as calculated by the SimaPro software.*

| Process | Unit | ALU window |
|---|---|---|
| Total of all processes | % | 100 |
| Remaining processes | % | 0,9532 |
| Crude oil I | % | 50,29 |
| Extruding alum I | % | 13,28 |
| Natural gas I | % | 11,63 |
| Electricity UCPTE oil I | % | 11,07 |
| Electricity UCPTE coal I | % | 6,519 |
| Electricity UCPTE nuclear I | % | 3,475 |
| Natural gas B | % | 1,458 |
| Aluminium ingots I | % | 0,857 |
| Powerplant lignite I | % | 0,684 |
| Steel high alloy ETH T | % | 0,5459 |
| Powerplant gas I | % | 0,2599 |
| Bauxite | % | -0,3014 |
| Aluminium raw bj | % | -0,3546 |
| Glass (white) B250 | % | -0,3628 |

| Process | Unit | PVC window |
|---|---|---|
| Total of all processes | % | 100 |
| Remaining processes | % | 4,409 |
| PVC suspension A | % | 62,03 |
| Steel high alloy ETH T | % | 41,64 |
| Electricity UCPTE Med. Voltag | % | 24,89 |
| Float glass uncoated ETH T | % | 15,88 |
| Extrusion PVC I | % | 6,885 |
| Recycling ECCS steel B250 | % | 5,677 |
| Heat diesel B250 | % | 5,285 |
| EPDM rubber ETH T | % | 4,153 |
| Electricity UCPTE gas I | % | 4,136 |
| Steel I | % | 2,105 |
| Bulk carrier I | % | 2,048 |
| Glass 100% recycled B | % | -3,012 |
| ECCS steel sheet | % | -9,875 |
| PVC P | % | -66,25 |

PVC window, however, no such single process dominates. The production of PVC suspensions contributes about 62% to the environmental index, the production of steel high alloy about 42%. PVC recycling reduces the index about 66%.

### 9.4.6 Single Score

The final step of the comparative LCA is a determination and comparison of single scores for both windows. In Figure 9.19 the environmental index for the PVC window is equal to 0.0139 kPt (thousands of eco-points), while for the aluminium window 1.25 kPt (thousands of eco-points). The ratio of environmental indices is approximately 1:90.

Thus a comparison of the environmental indices for the life cycles shows that the production, usage, and disposal phases of the aluminium window cause about *90 times* greater environmental load than the same phases of a PVC window.

### 9.4.7 Sensitivity Analysis

From the point of view of environmental protection, selecting PVC windows for both household and industry is recommended. However, uncertainties associated with data accessibility, reliability and relevance and the lack of an accepted methodology for LCA analysis makes the final outcome to be only qualitative. To examine how sensitive the results of LCA analysis might be to data quality and assumptions in the life cycle model, a *sensitivity analysis* was performed. Changes in the final score as a function of different technology applied in the production phase, the different lifetime, and different disposal scenarios were analysed.

### 9.4.8 The Influence of the Technology

In the life cycle of the aluminium window we have to assume which technology was used to produce the aluminium profiles. The technology selected from the SimaPro database and used in life cycle modelling refers to the production of aluminium parts of windows and cars. In the database it is called *extruding aluminium*. However, it is not known which technology was applied to extrude the profiles of the window analysed (this information was not available during the inventory analysis). In the SimaPro database there are two other technologies for aluminium extrusion:

- Aluminium extrusion – this technology does not encompass aluminium production.
- Alu tubes production – technology of the extrusion of aluminium tubes annealed at temperature 450 °C and coated inside and outside.

To investigate the influence of the production process we conducted a sensitivity analysis of the aluminium windows, in which the process of *extruding aluminium* was replaced by the processes of *aluminium extrusion* and *alu tubes production* in the production phase (Figure 9.20a). The effect of the analysis shows a dramatic decrease in the ratio of the indicators from 1:90 to 1:1.36 for *aluminium extrusion* technology and to 1:1.25 for *alu tubes production*. The sensitivity analysis shows that irrespective of which data we use the lower environmental index is ascribed to the plastic window, albeit 36 or 25% rather than 90 times. The sensitivity analysis shows the selection of the technology for aluminium profiles production is decisive for the environmental impact of the whole life cycle of an aluminium window.

### 9.4.9 Different Lifetime

Plastic and aluminium windows were designed to be in operation for a relatively long time, so we cannot determine precisely the length of the products' life cycle neither its disposal scenario. For the LCA analysis presented here, the estimated lifetime is 50 years for an aluminium window and 40 years for a plastic window.

To check if lifetime of the products influences the environmental profile of the windows, a comparative LCA was performed for shorter (30 years) and longer lifetime periods (60 years) for both products (Figure 9.20b). The functional unit

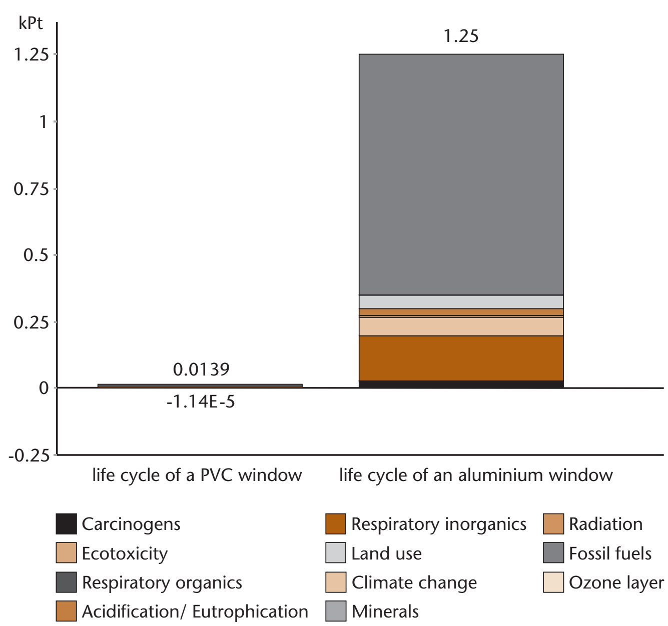



**Figure 9.19 Final environmental scores (index) for the life cycles of the Aluminium and PVC frame windows.** *The scores are shown for each of 11 different impact categories. Numerical values are in thousand eco-points (kPt). The method used was the Eco-indicator 99 (H) / Europe Ei 99 H/H using data for Europe.*

remains the same (a 50-year lifetime is the point of reference, see above).

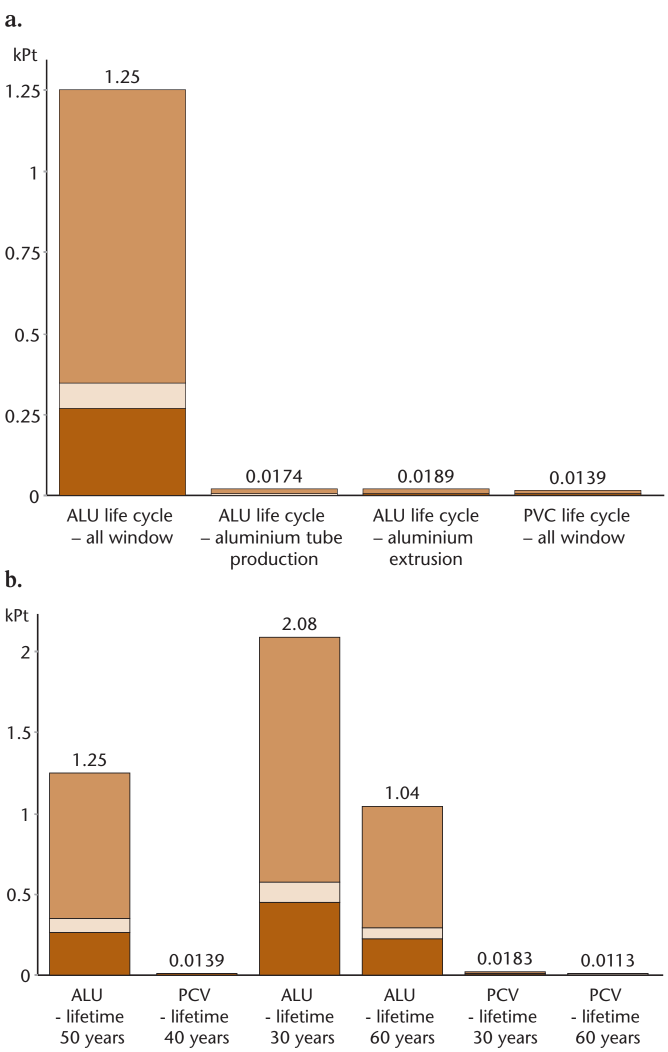
As we could expect, the longer the lifetime of the product, the better the environmental profile. The environmental index for aluminium window dropped from 1.25 for a lifetime of 50 years to 1.04 for a lifetime of 60 years and went up to 2.08 for a lifetime of 30 years.

However, this aspect of a life cycle hardly influences the results of a comparative analysis. A plastic window used for 30 years (environmental index 0.0183) is still much more environmentally friendly than an aluminium window used for 60 years (environmental index 1.04). The ratio of environmental indexes is now approximately 1:55.

## 9.4.10 Different Disposal Scenarios

Above we assumed a similar disposal scenario for both windows: plastic and aluminium elements, supports, handles, ferrules, anchors and panes are recycled, gaskets are discarded, partly incinerated and partly land filled, based on a Dutch scenario of municipal waste utilisation.

Different disposal scenarios did not significantly affect the environmental profiles of the windows (Figure 9.20c). The environmental index of the aluminium window did not change (~1.25), while for PVC windows it increased slightly from 0.0139 to 0.022, when recycling was reduced and land filling and incineration were increased. The result was expected as the production phase generates the strongest impact on the environmental index of both windows.



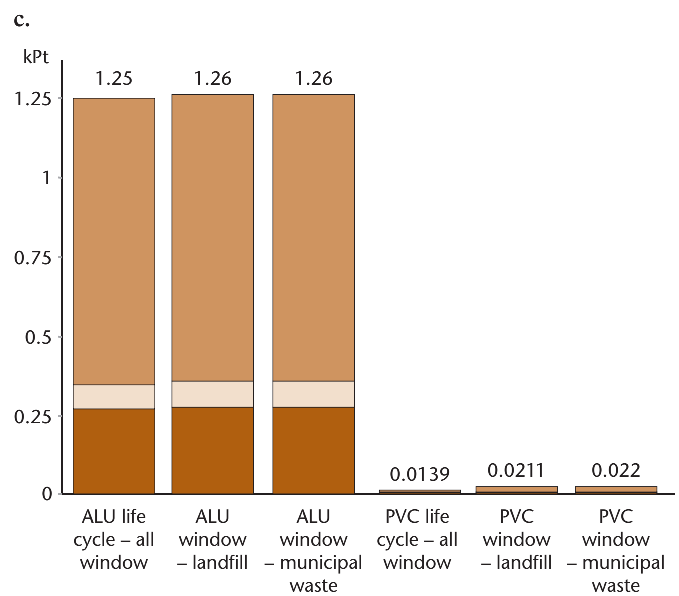




**Figure 9.20 Sensitivity analysis of the LCA analysis of the Aluminium and PVC frame windows for production method, life time and wasting method divided between three damage categories. a.** *Influence of the production process showing (from left to right) basic scenario, aluminium tube production, and aluminium extrusion. The environmental load of the PVC frame window production is shown for comparison.* **b.** *Influence of life time showing (from left to right) basic scenario, life times of 30 years and life times of 60 years.* **c.** *Influence of method for wasting showing (from left to right) basic scenario, land-filling, and municipal waste treatment with incineration. Numerical values are thousand of eco-points (kPt).*

Human Health  Ecosystem Quality  Resources

### Student Exercise

All steps in the "Windows" project, described in the book, can be analysed during classes with students. With this aim complete the following procedure:

Download a demo version of SimaPro directly from the CD attached to the book or alternatively at:
http://www.pre.nl/simapro/default.htm

To install the program from the CD, open the setup file at: CD\SP5Demo\Disk1\Setup.exe. You will be asked where you want to install the program. Advisably accept the default location at C:\ProgramFiles\SimaPro 5 Demo. If you prefer to install it somewhere else, please remember the location.

Now you can start SimaPro from the desktop (choose single-user analyst version). You are encouraged to run the Guided Tour, which is a comparative analysis of different models of coffee machine and is a standard SimaPro case study. Its aim is to get you accquainted with the most important features of the software.

SimaPro 5 demo gives you access to 8 database libraries (BUWAL 250, Data Archive, Dutch Input Output Database 95, ETH-ESU 96 System processes, ETH-ESU 96 Unit processes, IDEMAT 2001, Industry data, methods) and 2 case studies (Guided Tour, Tutorial with wood example). The demo version allows you to analyse already conducted projects. You are not permitted, however, to make any changes.

To get access to the "Windows" project you have to replace your database, which can be found in the SimaPro folder (C:\Program Files\SimaPro 5\Database\, unless you installed it somewhere else), with the database provided on the CD. Follow these instructions:

1. Open the SimaPro folder on your computer (C:\Program Files\SimaPro 5\Database\, unless you installed it somewhere else) and delete the whole folder "Database".
2. Copy whole folder "Database" from the CD and paste it at C:\ Program Files\SimaPro 5\.
3. Open the new database you have just copied to your computer and select all files.
4. Click once with the right button and select "properties" item. Untick "read only" checkbox.
5. Close the database and start SimaPro from the desktop.

Now, go ahead and run your classes on LCA on "Windows".

## Study Questions

1. Which part of the ALU frame window life cycle has largest environmental impact, and how can it be changed to reduce the impact.
2. Which part of the PVC frame window life cycle has largest environmental impact, and how can it be changed to reduce the impact.
3. List the parts of the life cycles of the two windows which have a negative environmental score (reducing environmental impact). What exactly do they consist of?
4. Describe how you go from inventory to characterisation to normalisation to weighting for a particular component in the process tree.
5. Explain the final environmental index, expressed in so-called eco-points in the eco-indicator 99 method.
6. The comparative LCA analysis of the two windows can be interrupted at each level in the sequence (characterisation, normalisation, weighting). Describe and give interpretation of differences in LCA score after each of these steps.

## Abbreviations

| | |
|---|---|
| ALU | Aluminum. |
| DALY | Disability Adjusted Life Years. |
| EPDM | Ethylene Propylene Diene Monomer (rubber). |
| PDF | Potentially Disappeared Fraction. |
| Pt | Eco-points. |
| PVC | Polyvinyl Chloride. |
| VOC | Volatile Organic Compounds. |

## Internet Resources

PRé Consultants: Eco-indicator 99
impact assessment & ecodesign method
http://www.pre.nl/eco-indicator99/

PRé Consultants: SimaPro 6 LCA software
http://www.pre.nl/simapro/default.htm

Aluminium production technology:
European Aluminium Association
http://www.azom.com/details.asp?ArticleID=1554

Polyvinyl Chloride production sustainability:
INEOS Vinyls Company
http://www.evc-int.com/she/waste.htm#pvcproducts

Polyvinyl Chloride production technology:
INEOS Vinyls Company
http://www.evc-int.com/worldofpvc/manufact.htm

# 10 Waste Management and Product Design

## 10.1 Waste Management Strategies

### 10.1.1 Reasons to Reduce Waste

In the life cycle of a product waste management is as important as resource management. Product developers should concern themselves with the end-of-life phase for several reasons.

Firstly, the magnitude and diversity of waste problems are increasing in our consumer society. At some stage it becomes too difficult to collect all solid waste in landfills. It is simply too much, too expensive to manage and too polluting. Among the most important environmental threats is leakage to ground water. Germany was the first country to restrict the dumping of waste in landfills for such reasons and to introduce rules and taxes to reduce waste. Later other countries in Europe followed. Today the EU waste directive applies strict rules to reduce the stream of waste to landfills.

Secondly society becomes aware that waste consists of natural resources, and that materials and energy must be used more efficiently and sustainably. There is a long tradition to fall back on. In pre-industrial society discarded material was not thrown away but used for some purpose. Products were repaired, or parts of it were used in new products or for new purposes; organic material was sent back to cultivated land, and burnable material was used for heating. One could simply not afford to be wasteful. Today reuse and recycling are again important.

But the most basic reason for a proper waste management – as with proper resource management in general – is that we need to reduce the material flows in our societies. Today a very large share of the material flows is linear, from the origin to the waste dump. This is not sustainable. In the longer term we need to improve waste management to make the material flow more cyclic, and reduce the absolute amount of material used in our societies drastically.

### 10.1.2 The Amount and Kinds of Waste

Waste may be solid, water-born or gaseous. Wastewater management will not be discussed here. Still, it should be pointed out that treatment of wastewater leads to the production of sludge, which is a resource for both energy production and nutrients. Wastewater may thus be treated as a resource, just like solid waste. Similarly, gaseous waste, sometimes called molecular waste, may be treated as a resource, e.g. when sulphur in flue

**In this Chapter**

gases is used for gypsum. More often it is not, while e.g. its heat content can be used in a heat exchanger.

Solid waste is an important part of the material flows, amounting to about one tonne per year per person. In general one third of the waste is generated by households and two thirds by industry, although it varies by country [Berg, 1997]. Thus in Sweden the relationships is close to 50:50, while in Poland industry generates close to 90% of the waste [Andersson, 2003].

The largest waste stream is created in connection with extraction of material from mines and quarries. This *mining waste*, typically sand, gravel, rock and other overburden, stays on the mining sites. Sometimes it is used for construction work, such as road building. Increased recycling will reduce this kind of waste as virgin metals then are less needed. Designers may reduce this waste stream by dematerialisation of products.

The *construction industry* releases an increased amount of waste, consisting of wood, metal, plastics etc. The proper use of this waste is an important issue in our societies, especially as construction is increasing greatly. This waste stream is very much affected by the way houses are constructed. Since houses and infrastructure account for an important part of the material flows in our societies even a small slimming of the material used for single buildings is significant.

*Municipal waste* is fairly similar in all countries in the region. Differences are due to the relation between commercial vs household as sources of waste. Packaging material is an important part of household waste, as is organic waste from kitchens. Packing materials can easily be reduced by design decisions.

The *size* of the waste streams in our societies is not decreasing, but the management of the wastes is changing. Less and less ends on the landfill as will be described below.

### 10.1.3 Practices in Waste Management

Before the industrial age the farming society's waste management practices were, as mentioned, well established. Waste was taken care of as a resource. In the cities, however, waste was more often just thrown out on the street. With increasing urbanisation this became impossible. Landfills developed, although with bad environmental consequences, such as leakage to ground water, bad smell and emission of gases. In addition many did not use the organised places for waste, but threw their waste out anywhere. The bad smell of so-called pits in many industrial towns was terrible [Sörlin and Öckerman, 2002].

During the last few decades waste management has been more organised. Improper deposition of waste leads to fines (when detected and registered). But bad habits still remain, especially when it is costly to get rid of waste. It is especially serious to leave old cars in the forests. Here cars and other metallic and plastic waste not only destroy nature and threaten wildlife, but also pollute. In a 2004 survey the national NGO *Keep Sweden Tidy* found one hundred thousand waste cars in the country. The Baltic Sea region-wide NGO *Keep Baltic Tidy* for several years has made efforts to keep waste away from beaches and the Baltic Sea itself. Marine waste is very destructive for marine life and fish reproduction (see Internet Resources).

Proper waste management requires that waste be sorted according to fractions which are collected and treated separately. Experiences from sorting already collected waste are in general very negative. Instead, solid waste must be sorted by the producer, household or other business or organisations. Sorting of waste by households is now legally required in some countries and encouraged in others. However the infrastructure required for taking care of the sorted waste is lagging behind in many cases. All these factors are needed for proper waste management.

The reuse of products and recycling of materials is the preferred option for reducing waste streams. Again this can hardly be efficient unless the original user of the products helps to achieve this. Recycling is improving in many places, stimulated by increased market prices for such material as scrap metal, plastics, and paper.

In industry the use of waste is most efficient in so-called industrial symbiosis. Here the outflow from one factory is used in a second one. In some cases it is simple, e.g. steam produced at one site can be used as an energy source in another. In other cases it is more sophisticated, as when sulphur in flue gases in a power plant is used to produce gypsum boards for the construction industry. Also here there are good economic and environmental reasons to take care of waste as a resource properly.

### 10.1.4 Business and Waste

One of the most salient new elements in ecodesign is that it forces businesses to start thinking about what happens to the product after it leaves the factory. Furthermore, businesses have to develop a scenario for what happens to the product when the user no longer wants to use it: this is the end-of-life phase. The end-of-life of a product refers to all that can happen to a product after it has been discarded by the initial user. Is the product taken back and reused? Are useful components removed from the product for reuse, or are only the materials reused? Is the entire product incinerated or is it just dumped on a rubbish tip?

Partly because of the developments in legislation on manufacturers' responsibilities and the increased level of environmental awareness, all entrepreneurs need to be able to answer the above questions. The view taken by management of the end-of-life system of the product is a strategic consideration which depends on consumer behaviour, infrastructure, and local and international legislation. It is also necessary to determine at the product level if an intended end-of-life system is technically and economically feasible. Subsequently, it is the designer's job to redesign the product so that it is suited for the chosen end-of-life system.

End-of-life systems can been seen as an important part of producer responsibility. Industry, of course, wants to achieve environmental improvement at the lowest possible cost.

## 10.2 Integrated Waste Management

### 10.2.1 The EU Waste Management Hierarchy

*Integrated waste management systems* address the whole municipal waste stream, the materials to be recovered and the optimal treatment methods to be employed.

Figure 10.1 visualises that a waste management system includes material recycling, biological treatment, such as composting or biogasification, and the energy-from-waste methods. All of these are potentially feasible in different situations, and none should be ruled out.

It must be noted though that integrated solid waste management systems ought to be developed at the local level because only then can they be optimised to the local conditions. These differ from region to region and from urban to rural areas. The environmental management tool of a Life Cycle Inventory (Figure 10.1) can be used to develop the optimum solution for a specific location [McDougall et al., 2001].

The EC Waste Directive has established a *waste management hierarchy*, a list of options to treat waste of which the first is the preferred and the last should be as far as possible avoided. Policy measures, such as landfill taxes, have been implemented to achieve this. The hierarchy contains the following eight items:

1. Waste reduction
2. Reuse
3. Recycling
4. Composting
5. Biogasification
6. Incineration with energy recovery
7. Incineration without energy recovery
8. Landfill

It is not always wise to see this as a rigid hierarchy, but rather as a set of guidelines or a menu of options. This allows for the flexibility required when selecting the most environmentally effective and economically efficient method of waste management for a specific geography/location. There is not always a scientific or technical basis for listing the waste treatment options in this order, for example, why materials recycling should always be preferred to energy recovery. Waste policy needs to be aligned with overall environmental policy objectives.

In practice one has to use a set of methods. The hierarchy approach as such does not allow a comparison of the environmental advantages and disadvantages of the combination of different municipal solid waste treatment options. In addition the hierarchy does not address costs and therefore does not lead to or promote economically efficient waste management systems.

Packaging waste policy is sometimes discussed separately, but in fact it should be part of an overall waste policy.

### 10.2.2 Strategies for Optimising Product End-of-life

In the overall end-of-life system two strategies (see Chapter 3) were especially relevant. They are:

Ecodesign strategy 6: *extending life-time*, Prevent the user from discarding the product – for instance by extending its life.

Ecodesign strategy 7: *end-of-life system*.

- Reuse the product as a whole, either for the same or a new application.
- Reuse sub-assemblies and components by remanufacturing and refurbishing.
- Recycle the materials involved by:
  - recycling in the original application (primary recycling).
  - recycling in a lower-grade application (secondary recycling).
  - recycling of plastics by decomposing their long plastic molecules into elementary raw materials which are subsequently reused in refineries or for the production of petrochemicals (tertiary recycling, also known as feedstock recycling).

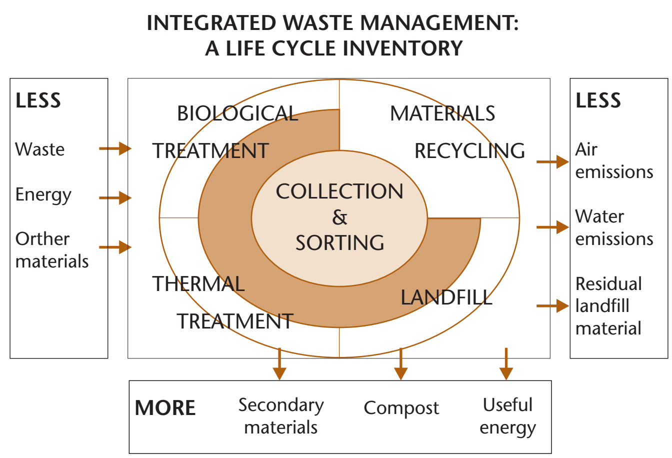



**Figure 10.1 Integrated waste management.** *The total waste emitted during the end-of-life of a product [McDougall et al., 2001].*

## Box 10.1 Step-by-step Plan for the End-of-life Analysis of a Product

When planning for end-of-life design guidelines in product redesign, the current product – the one to be redesigned – will be used as a *reference product*. The guidelines to determine the end-of-life destinations are described in the flow chart in Figure 10.2.

Product parts can have different end-of-life destinations. It is entirely possible that some parts can be reused, that e.g. a housing can be disassembled and recycled, and that the remaining parts can be mechanically processed. This will depend on how different parts age and on how easy it is to free parts from the product.

When the reference product is run through the chart, an estimation of the end-of-life destinations of the product parts can be made. For example, it becomes clear which parts can be recycled. On the basis of these estimations, the management policy and the interactions between these two, guidelines for redesign can be drawn up. The decision points in the chart are described below.

**1. Will the material cycles be closed?** The entry to the chart is the strategic choice for a certain end-of-life system. This choice determines whether or not the product will be kept in the loop and therefore roughly what the end-of-life system will be. After this the consequences for the reference product will be examined.

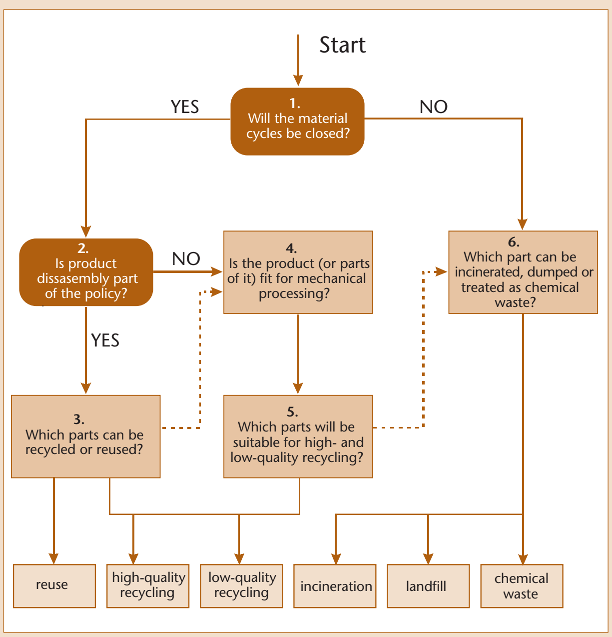



**Figure 10.2** *Flow chart with general guidelines to determine the end-of-life destinations for a product. [TNO Industry, Delft, The Netherlands].*

**2. Is product disassembly part of the policy?** Disassembly is done for two reasons. Firstly, it is important to obtain the purest form of secondary materials possible. Secondly, hazardous substances must be isolated so they do not contaminate other material or exert too great an influence on the environmental impact of the whole product or on the financial return.

Disassembly is done by hand and is therefore costly. In Western Europe the total industrial rate is approximately Euro 0.5/minute (including wages, overheads and housing). Such rates imply considerable restrictions on the amount of material that can be retained from disassembly.

The decision whether or not to disassemble will be taken on the basis of a rough estimation of the entire product.

**3. What parts can be reused?** Parts can be reused when the technical life of the product is longer than the economic life. Furthermore, it is important that there is a market for these parts – a current market or a possible future market. The value of secondary parts depends strongly on their application; if this is at the same level as in the original application, reasonable prices (20-60% of the original price) can be obtained. The price falls rapidly for lower grade applications. Generally, a part cannot be reused if it fulfils only an aesthetic function.

**4. Is the product (or parts of it) fit for mechanical processing?** Material not detached in the disassembly process usually ends up in a combined form on mechanical processing lines. This processing consists of two steps: reduction of the materials to small sizes (by compaction or shredding, for example) and then separation.

Size reduction is essential to break down the different sorts of material and reduce volume. This can be done, for example, in hammer mills, cutting mills or by means of cryogenic milling. Separation is achieved in several stages. First, materials containing iron are separated magnetically. Materials containing aluminium are then separated by eddy current processes. Several other separation methods are then used to separate copper-content materials, mixed plastics and precious metals.

**5. Which parts will be suitable for high- or low-quality recycling?** Of product parts containing ferrous materials, 95% of the magnetic material can be made suitable for high-quality recycling by means of magnetic separation. High-quality recycling of other parts (and the remaining fraction) can be achieved when the material consists of more than 95% of thermoplastics of one kind. When this 95% consists of exactly two materials, the part can be low-quality recycled. Parts that contain less than 95% of thermoplastics can be considered for other separation techniques. Of these parts, 60% of the precious metals can be separated and recycled with high quality, and 80% of the aluminium and 90% of the ferrous materials can be recycled with low quality. Other parts and the remaining fraction can be considered for incineration and landfill.

**6. Which parts can be incinerated, dumped or treated as chemical waste?** When a choice between incineration and landfill has to be made, the calorific value must be considered. Materials with a high calorific value produce energy during incineration, so this is therefore preferable to landfill. Metals produce zero energy while plastics produce 40 MJ/kg. The best solution for plastic parts which cannot be reused or recycled is therefore incineration. Generally, when the calorific value is more than about 8 MJ/kg, incineration is preferred.

If the product is not stripped of its toxic components, the entire product has to be treated as chemical waste. This will involve certain costs. Separation of parts will be attractive when the costs of dismantling and processing of toxic parts, less the economic value of the remaining non-toxic materials, are lower than the costs of processing the entire product (see also Step 2).

*Results of the flow chart* e.g. on the feasibility of disassembly and mechanical processing, can influence the decision on whether or not to close material loops. Once we have looked in detail at the consequences (on the level of product parts), strategic decisions on take-back, reuse and recycling can be made. When this feedback has been made, priorities within the end-of-life system can be set and the product optimised.

- Safe incineration with energy recovery and waste disposal:
  - incinerate non-reusable materials by using energy generation technology and good flue gas purification (quaternary recycling, also called thermal recycling).
  - incinerate non-reusable materials without energy generation technology but with flue gas purification.
  - dispose of the residual material in a controlled fashion as solid waste.

Incineration without flue gas purification and uncontrolled dumping fall under the category of prohibited options.

Priorities have to be set when developing an end-of-life system. This is necessary because there are usually numerous design options, some of which may conflict. Priorities also have to be set because conflicts can occur when the two other main options for ecodesign, the reduction of materials usage and energy consumption, are simultaneously taken into consideration. Examples:

- Reduction of the energy consumption of any device through miniaturization and integration of electronics generally leads to a lower end-of-life value. This is because useful components become difficult to detach after the product's first life.
- If a product is usually discarded due to a weakness resulting from poor construction, the design should be improved rather than searching for ways of reusing the product or replacing the faulty component.

### 10.2.3 Solid Waste Incineration

The strategies above are listed in preferential order. However, recycling or safe incineration with energy recovery is sometimes preferable to reuse or remanufacture. Examples:

- The energy consumption of an electric appliance (such as a television set) has been reduced to such an extent over the past ten years that it no longer makes sense to promote the reuse of the appliance for more than ten years.
- For materials containing toxic organic compounds, safe incineration (destruction) is better than recycling.

Which of the above environmental priorities apply to specific end-of-life systems is determined by the cascade concept: the aim is to keep a material in the highest grade application for as long as possible. An example in the chemical industry is that the high-grade raw material natural gas is not used initially for heating but is first used for other purposes:

1. The gas is initially used to produce plastics.
2. These plastics are then used in high-grade products.
3. When these products have been disposed of, the plastic is recycled and used in a low-grade product.
4. After this product has been discarded the plastic is used as packaging material.
5. This packaging material is then converted, for example by feedstock recycling, into low-grade fuel.
6. Finally, this fuel is used to generate energy.

## 10.3 Preparing the Product for End-of-life

### 10.3.1 Product End-of-life Analysis

Design for the end-of-life of a product can be analysed systematically. A method for this is described in Box 10.1. It is summarised in Figure 10.2. The parts of a product are analysed separately in a six-step system. The analysis should define the best answers for questions such as should a product be designed to make disassembly possible; should parts be made to be exchangeable and thus the product itself possible to repair; should parts be possible to reuse; should the product be designed so that the material is possible to recycle; should some (all) material be possible to incinerate for energy recovery.

The results from the flow chart (Figure 10.2) will feed into the design strategies and make optimal decisions on the design.

### 10.3.2 Optimising the Product According to End-of-life System

A number of design rules can be formulated to optimise the product according to the end-of-life system. Chapter 3 *Strategies for Ecodesign*, provides design rules for extending the life of a product, product reuse, remanufacturing and refurbishing, and recycling.

By following the priorities set above and elaborating them with the steps in Chapter 3, a realistic end-of-life strategy can usually be obtained. This can be quantitatively underpinned by using additional methods such as life cycle assessment, an analysis of life cycle costs and/or an analysis of the end-of-life costs.

*Life cycle assessment (LCA) methodology* has as yet been unable to generate complete environmental profiles for end-of-life problems due to methodological problems e.g., such as difficulty in estimating the system boundaries for recycling. Secondly, it is not yet clear how we should deal with "enclosed" toxicity. How should toxicity which is released into the environment, for example through leaching from buried waste, be included and on what time scale (1, 10, 100, 1000 or 1 million years)? Thirdly, it is not clear how "emissions" formed by the physical presence of a rubbish mountain (which does not fit in any landscape) should be included. A fourth problem is that reliable data on the environmental impact of collection, separation and recycling processes of waste are still inadequate (see further Section 10.4).

In Table 10.1 very approximate figures are given for the reduced impact of recycled materials. The figures are based upon eco-indicator values for the environmental impact of materials [Goedkoop, 1995]; transport energy for collection is included. It is evident that the use of recycled material has a beneficial effect on the environment.

### Box 10.2 A New Waste Strategy

#### Making Europe a Recycling Society

The European Commission proposed in 2005 new strategies on resources, and the prevention and recycling of waste. The proposal is revising the 1975 Waste Framework Directive to set recycling standards and to include an obligation for Member States to develop national waste prevention programmes.

Environment Commissioner Stavros Dimas said: "Waste volume has been disproportionately increasing, outpacing even economic growth. Waste generation, disposal and recycling are of concern to all of us: individuals, companies and public authorities. Now is the time to modernise our approach and to promote more and better recycling. Our strategy does precisely that. EU environment legislation has helped improve the way we dispose waste and recycle specific waste streams, such as municipal waste, packaging, cars and electric and electronic equipment. Waste management has moved a long way from being a dirty, polluting business. High standards exist for landfills and incinerators. Industry now seeks to make a profit from waste instead of dumping it."

However, waste generation in the EU is estimated at more than 1.3 billion tonnes per year and is increasing at rates comparable to economic growth. For example, both GDP and municipal waste grew by 19% between 1995 and 2003. One consequence of this growth is that despite large increases in recycling, landfill – the environmentally most problematic way to get rid of waste – is only reducing slowly. What is needed now is to modernise and widen EU waste policy in the light of new knowledge. Companies and public authorities need to take a life-cycle approach that does not only look at pollution caused by waste. It must also take account of how waste policies can most efficiently reduce the negative environmental impacts associated with the use of resources through preventing, recycling and recovering wastes. To move towards this objective EU waste law must create the right regulatory environment for recycling activities to develop.

The main elements of the proposed revision of the Waste Framework Directive are:

- Focusing waste policy on improving the way we use resources.
- Mandatory national waste prevention programmes.
- Improving the recycling market by setting environmental standards that specify under which conditions certain recycled wastes are no longer considered waste.
- Simplifying waste legislation.

Further measures are programmed for the next five years to promote recycling and create a better regulatory environment for recycling activities. An Impact Assessment accompanies the strategy.

*Text extracted from the press release at: http://europa.eu.int/comm/environment/waste/strategy.htm*

### 10.3.3 End-of-life Costs

When making life cycle cost calculations it will appear that the end-of-life costs make up only a small part (1 to 7%) of the total costs. The obvious implication, that end-of-life costs are insignificant, is incorrect. This is because one must not only look at the absolute size of the amounts but also at the degree to which they can be influenced. There is a big difference here in comparison with the other items of expenditure: whereas ways to reduce the costs of production and transport, for example, have always been sought (and indeed many options to achieve this have already been found), end-of-life expenditure has only more recently been studied.

It is important to calculate the *end-of-life costs* on the basis of price quotations from service providers in the field of logistics and recycling/processing. The company itself must also build up an insight into end-of-life costs. Experience has shown that this generates a great deal of understanding of the subject and stimulates environmental design improvements.

Data must be gathered on rates charged for waste and incineration while the value of the secondary material must also be known. For metals, scrap prices are related to the prices quoted on the London Metal Exchange, for plastics the value of high-grade secondary material is approximately 60 to 70% that of the new price.

A significant question for complex products is: which components must be separated and which parts should be eligible for mechanical processing? A rough estimate can be made with the help of Table 10.1 and on the basis of self-established standard disassembly times and current hourly rates.

Calculating end-of-life costs for packaging is relatively simple since agreements have been reached in several countries for the return and processing of packaging and the economy of this.

## 10.4 Life Cycle Assessment and Waste Management

### 10.4.1 Waste Management and the Beginning of LCA

Concern about solid waste and waste management was one of the driving forces behind the development of Life Cycle Assessment methods in the 1970s and the following years (Box 5.1). Issues such as which were the best options, recycling or incineration, returnable cans or non- returnable cans, were studied by LCA methods back in the 1970s. Packaging waste in general has been a major topic in many LCA studies in the 1980s and 1990s. The results of the studies have been the basis for deciding on recycling of products and its parts, especially containers, as well as recycling of materials, such as glass, paper and metal.

The application of LCA to packaging has been enlarged to include the study of wastewater, especially the use of sludge, which often ends up on landfill, including if the separation of urine is a good environmental option. Other LCA studies have been concerned with hazardous waste, such as solvents of different kinds.

Even if a majority of studies have been concerned with household or consumer waste, industrial waste has also been studied. Major questions have been the comparison of different recycling options. Here it is often less complicated than consumer waste since open loop recycling, where the systems becomes very large and complicated, is largely avoided.

LCA studies have been concerned with waste in general, with materials such as paper or metals, or with individual products. Waste studies are of importance for municipalities which normally have the responsibility. Individual materials can be studied to evaluate options such as energy from incineration, or even fuel production from plastics.

The options for end-of-life for products are often multiple and complicated. It is simpler to evaluate not whole material but rather defined products. One of the larger difficulties is open loop recycling, that is the waste form one product is fed into a second product, often of lower quality, such as packing material from newspaper,

### 10.4.2 Difficulties in LCA of Waste Management

Waste has to be dealt with in almost any LCA since it is part of the product life. A number of difficulties are then typical and appear every time. One way to avoid these difficulties, sometimes used in early LCA studies, was simply to count waste as an impact category and make no further analysis. This is not common any longer.

**Table 10.1 Reduction of environmental load by recycling.**
*Reduction of environmental impact when recycled materials are preferred to virgin materials according to Eco-indicator 95 [Goedkoop, 1995].*

| | |
|---|---|
| 100% recycled glass has an impact which is | = 0.8 x that of completely new glass |
| 100% recycled iron | = 0.4 x that of completely new iron |
| 100% recycled plastic/paper/cardboard | = 0.4 x that of completely new material |
| 100% recycled copper | = 0.25 x that of completely new copper |
| 100% recycled aluminium | = 0.1 x that of completely new aluminium |

## Box 10.3 Recycling Electronic Waste – Mobile Phones

### Eco-phones?

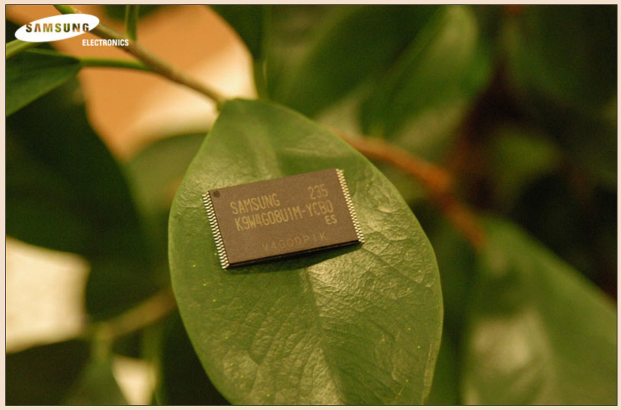



**Figure 10.3 Lead-free semiconductor from Samsung.** *4Gb NAND Flash memory to be used in products such as mobile phones, digital still cameras, handsets, MP3 players and USB Flash drives, etc. Photo: © Samsung.*

The market for electronics is steadily increasing, and technical development are very intensive with dramatic increases in product quality. A significant feature is also that the life-cycle of some electronic products is growing shorter. A computer bought today is often considered old after just a few years of use. New and more powerful products are launched with double-sized hard discs, quicker CPUs and, on the bonus side, often also at reduced prizes. The result is a huge and quickly growing mountain of electronic waste and with a material content which is often considered harmful for our environment. There are an today estimated over 1 billion mobile phone subscribes worldwide. The chairman of Nokia company, Jorma Ollila predict that this figure will increase to 2 billion in just a few years time. See article: *http://www.siliconindia.com/shownewsdata.asp?newsno=23296&newscat=Technology*

Research from the UK also suggest that users replace their mobile phones after only having used them for a year and a half. In Europe about 105 million phones are replaced every year. If these were placed one on top of the other the height would equal Mount Everest multiplied by 324!

Theoretically speaking, the life-cycle of these phones could be enhanced by quality measures that would make them last many, many years after they are thrown away in favour of smaller phones with increased functionality. If we, however, have to accept that many electronic products will have a short period of productive life, other measures must be taken to safeguard that computers, cell phones and other electronic products are manufactured, used and recycled in an environmentally friendly way. As mentioned legislative measures have been taken to increase producer responsibility for products and many initiatives have also been taken, for example the WEE and RoHs directives.

Starting on the production side, most electronic products today are based on the technology of semiconductors. These are used in everything from computers and washing machines to cell phones and portable mp3-players. Semiconductors have until now contained lead and halogen compounds which now, in accordance with the WEE and RoHs directives, are scheduled to be phased out in Europe after 2006.


**Figure 10.4 The Nokia 6650 phone.** *"Designed for recyclability" is the heading on one of Nokias web pages presenting it as a case study for ecological product design. Photo: © Nokia. See case study: http://www.nokia.com/nokia/0,6771,27593,00.html*


**Figure 10.5 Recycle your old phone.** *One of Fonebaks recycling-collector boxes for mobile phones set up in a store. Photo: © Fonebak pic.*

**Figure 10.6 Researchers compost old mobile phones and transform them into flowers.** *Dr Kerry Kirwan at the University of Warwick showing the old mobile telephone cases disintegrating and growing into flowers. Photo: © University of Warwick.*

A few years ago Samsung, as the first company in the world, developed a new technology to produce lead-free semiconductors, and developments are under way also to phase out halogen compounds.
*http://www.samsung.com/Products/Semiconductor/DivisionPolicy/Ecoproduct/*

Another example of innovation are the batteries in mobile phones. Today most of them contain lithium. Recently the recycling company Umicore SA in Belgium developed a closed-loop-solution for sustainable recycling of Li-ion batteries with a patented process called VAL'EAS™. Umicore was presented with the European Environmental Press (EEP) Association's Gold Award 2004 (conferred in collaboration with European Federation of Associations of Environmental Professionals (EFAEP) and Pollutec) for their innovative environmental technology.
*http://www.recyclingsolutions.umicore.com*

Sustainable recycling of electronic waste is becoming increasingly important, and for mobile phones efforts are being made in many countries. One example is the English company Fonebak, with branches in several countries in Europe. According to the company the phones handed in to them are 100% recycled.
*http://www.fonebak.com/*

Efforts to increase recycling of products by using biodegradable material instead of ordinary plastic is ongoing, and one interesting example of this is the research done by Dr Kerry Kirwan at the University of Warwick.

Together with PVAXX Research Development Ltd and Motorola he has created a mobile telephone case made of biopolymers that, when discarded, can be placed in compost in such a way that just weeks later the case will begin to disintegrate and turn into a flower.
*http://www2.warwick.ac.uk/fac/sci/eng/ug/elect/xs/xscase1/*

## Box 10.4 Waste Management Initiatives – Examples

**1. Heinz adopt lightest steel can 2006**
HJ Heinz, in conjunction with Impress Group BV, has carried out successful trials of a new light-weight "easy open" steel can end. The new end has a thickness of just 0.18 mm – beating the lightest food can end previously available by 0.02 mm and creating a new "best in class". Heinz now intends to convert its entire range of 200 g and 400 g cans to use the new lightweight can end, a move that will eliminate around 1,400 tonnes of steel waste annually. If this is taken up across the sector, the scheme could reduce UK household waste by as much as 28,000 tonnes per year.

**2. Belgian tyre producer responsibility gets off the ground**
Recyctyre, the Belgian take-back organisation for tyres effective from 2005, is funded by a levy on new tyres, EUR 2.4 for smaller tyres and EUR 10.3 for larger tyres. 65,500 tonnes of the 80,380 tonnes marketed were recovered for recycling, a collection rate of 81.5%. Car and van tyres were the major contributor. The recovered tyres were treated as follows: energy recovery 36.9%, granulation 30.7%, exported for treatment 15.2%, re-treading 4%, re-use 2.4%, other treatment 10%.
*http://www.recyctyre.be*

**3. US C&A's carpet recycling programme**
C&A Floorcoverings Company is mining buildings for resources instead of the Earth. It has recycled more than 50,000 tonnes of reclaimed vinyl and vinyl-backed carpet, since it introduced the Infinity Initiative 10 years ago. C&A's recycles any post-consumer vinyl-backed carpet, regardless of original manufacturer, into 100% recycled content backing for new ER3 (R) floor coverings. Containing a minimum of 25% post-consumer carpet, the remaining 75% of the ER3 backing system consists of post-industrial waste generated during carpet manufacturing and industrial waste from the automotive industry. C&A instituted FLOORE is a "buy-back" programme offering customers financial incentives to return and recycle their old vinyl-backed carpet.

**4. Scottish business recycling directory on-line**
The Scottish Waste Awareness Group (SWAG) has produced an on-line recycling directory for businesses throughout Scotland. This web based tool is accessible via their web site. Businesses can search for reuse and recycling services by location and material to find out what is available to them in their local area. A range of service providers are included such as local authorities, the private waste management sector, and community sector organisations. The web site also contains a number of useful links to other initiatives and organisations that are working with businesses to facilitate resource efficiency, such as Envirowise and the Business Environment Partnership (BEP).
*http://www.wasteawarebusiness.com*

**5. Japanese Sekisui House achieves zero waste at new construction sites**
Sekisui House, a leading Japanese home builder, achieved zero waste at its new home construction sites in July 2005. At each construction site, waste is sorted into 27 categories and carried to the company's recycling centre by delivery trucks returning from the site. These resources are further broken down into about 60 categories at the recycling centre.

Sekisui House already achieved zero waste at all of its six factories in May 2002. Utilizing their existing recycling routes, the company has since successfully established a new system for construction waste. Some items are entrusted to outside recyclers depending on the type of material; iron, aluminium and concrete are recycled for use as building materials, and resin is recycled into pellets. Sawdust and degraded resin are processed at the company's own facilities and recycled into roof battens and interior materials.

Such efforts by Sekisui House have also helped reduce waste generation at construction sites. The average amount of waste from a construction site was reduced from about 2,900 kilograms in 2000 to about 1,800 kilograms in July 2005. Cost reductions through zero waste reached 39 million yen (about U.S.$350,000) in July 2005 alone. The company expects costs to be reduced by about 250 million yen (about U.S.$2.2 million) in the second half of its fiscal year ending in January 2006.

**6. British Government and magazine industry strike producer responsibility agreement**
The Periodical Publishers Association (PPA) and the Minister for Local Environment signed a producer responsibility agreement for the magazine sector. The agreement will increase the recycling rates for post-consumer magazines by 30% within eight years. Latest industry figures show that around 40% of magazines are currently recycled by consumers – many of them going to make up recycled-content newsprint for the newspaper sector. The agreement targets increasing this rate to 50% by 2007, 60% by 2010 and 70% by 2013. The agreement also endorses the current practice of unsolds going directly into the recycling process and work with local authorities and the public to promote recycling. Currently more than 500 magazines are carrying the Recycle Now logo.

*Source: Resource Recovery Forum News service, 2005. http://www.resourcesnotwaste.org*

*Open loop recycling* is one of these difficulties. An open loop is when a product waste is used for a new product or a new purpose, which in turn may be used for a third purpose or product. The common way to deal with this issue is systems expansion, that is, the model has to include the new products. However, this may be difficult and lengthy and setting system boundaries may be a problem.

*Multi-input allocation* refers to the recurring difficulties that waste treatment mostly is done on a mixed waste and thus it is problematic to know what happens to the product waste under study. Waste incineration gives rise to emissions which need to be allocated to different parts of the process. These emissions are very dependent on the conditions under which the incineration is done. Thus chlorinated hydrocarbons such as dioxins, or carbon monoxide are not generated if conditions are right.

*The time horizon* is also problematic to deal with. The processes in landfills are very long, maybe centuries, and not at all comparable to what is common in industrial processes. The time over which data exist is about one century, and this is the time horizon used in LCA. One way to deal with the problems is to use weighting.

### 10.4.3 Waste Management Models

Several models have been developed to serve as generic, generally applicable, tools for deciding on waste management, either for municipalities using them for consumer waste in general, or for production waste in industry, or for specific products. Many of these models also provide additional data, for example, on cost calculations and substance flows analysis. The models typically consist of models of partial processes, such as collection and separation into fractions, incineration, composting, gasification and landfilling. The results of the model are useful to support multi-criteria decision support analysis (MCDA). They are useful tools for a municipality to track how it fulfils the obligations of the EU waste directives. In Sweden – it will be similar for all of the European Union – municipalities are requested to deliver waste management plans; these are also supported by the models.

Among the models intended for municipal waste management is the Canadian ISWM (Integrated Solid Waste Management) [Mirza, 1998]. The models typically contain LCI data and cost data for various waste processing alternatives and sometimes optimisation tools. Outdata includes the environmental impacts of the waste treatment. The Swedish ORWARE model developed by Eriksson et al. [2002] includes, in addition to the above, wastewater treatment processes as well.

The CHAMP [Mellor et al., 2002] is part of a model used for specific materials. CHAMP was developed to study plastics, polymers, which is more complicated and multifaceted than paper, glass or metals. It is compares options such as extraction, polymerisation, blending and production of fuels (Figure 10.2).

## 10.5 Some Examples of European Waste Management

### 10.5.1 Waste incineration

Despite EU policy to divert biodegradable waste from landfill, landfilling remains the dominant method used in Europe – approximately 50% of the 243 million tonnes of municipal solid waste generated in EU-25 each year is still landfilled. There is still public reluctance to the *waste-to-energy (WTE) plants* as a safe treatment option. However approximately 50 million tonnes of waste is currently thermally treated each year in about 400 WTE plants in Europe. This is enough energy to supply electricity for 27 million people or heat for 13 million.

*http://www.earthscan.co.uk/news/article/mps/uan/513/v/5/sp*

### 10.5.2 Recycling Examples

The European Association of the Rubber Industry (BLIC) reports that each year approximately 3 million tons of *used tyres* need to be treated in Europe. Material recycling expanded its share from 5 % in 1992 to 28% in 2004. The use as alternative fuel has increased from 14 to 30%; the EU total recovery rate reached 79% in 2004.

The non-profit European association Petcore has announced that European *post-consumer PET* collection rates reached 665,000 tonnes in 2004, representing an 8.5% increase over the previous year. Germany, France and Italy together delivered 60% of these. Petcore expects that by 2010, more than one million tons of European PET will be collected and recycled. The European markets for recycled PET are gradually moving towards high quality applications. More than 90% of polyester strapping is nowadays made of recycled PET, using 11% of the collected bottles. Packaging material like thermoformed polyester and PET containers accounted for 23.2% of the market, and polyester fibre 65%.

In 2004, EBRA's, European Battery Recycling Association, 15 members recycled 23,900 tonnes of *used portable batteries and accumulators* and more than 4,000 tonnes of used nickel-cadmium (Ni-Cd) industrial batteries, making a total of 27,946 tonnes, which represents a 36% improvement on 2003. This increase is due notably to the arrival of five new members in the EBRA fold, accounting for the recycling of more than 8,000 tonnes of batteries and accumulators in 2004. Recycling of nickel-cadmium batteries (industrial and portable) increased most sharply between 2003 and 2004.

### 10.5.3 Producer Responsibility and Waste Collection

The mentioned companies Blic, Petcore and EBRA are examples of non-profit industrially owned companies for managing a waste common for an industrial sector. The creation of such companies is prompted by EU and state legislation on producer responsibility. These appears in many different branches.

The EU Directive on *Waste from Electrical and Electronic Equipment (WEEE)* requires all EU Member States to introduce specific rules for collection, waste treatment and recovery of electrical waste, and to place responsibility for these matters on producers and importers. Danish legislation will affect producers of refrigerators, alarm clocks, electric toothbrushes and other electronic equipment from April 2006. In future, new products must be labelled and producers must pay for treatment of the waste, rather than the municipalities paying for it, as is the case today.

More than a decade has passed since *Producer responsibility* was introduced in Sweden in 1994. The recycling level, then some 40%, has since increased to around 67%, based on the Packaging Directive criteria. 49% of the packaging waste goes to recycling, and another 9% to energy recovery. Only glass and corrugated cardboard, however, have reached their recycling targets. Aluminium, with a recovery rate of 27%, has a target of 70%. Only 57% of agricultural plastic has been recycled. 85% by weight of scrap vehicles were reused or recovered in 2004.

### 10.5.4 Dematerialisation and Waste Reduction

Over 2.2 million tonnes of *post-consumer steel packaging* were recycled in Europe last year, a recycling rate of 60% in the enlarged EU25. In Central and Eastern Europe, according to the level of collection infrastructure in place, recycling performances of Green Dot systems ranged from 11% (metals) in Lithuania to 43% (steel) in Hungary. Over the last 10 years, more than 16 million tonnes of steel packaging has been recycled, saving 40 million tonnes of $CO_2$ emissions, equivalent to the $CO_2$ emissions of 22 million cars, travelling an average of 10,000 km.

*Source: Resource Recovery Forum News service, 2005. http://www.resourcesnotwaste.org*

## Abbreviations

ISWM Integrated Solid Waste Management.
LCC Life Cycle Costing.
MCDA Multi Criteria Decision support Analysis.

## Study Questions

1. Describe the relation between waste management and product design.
2. Describe how end-of-life design is using integrated waste management strategies.
3. Explain the sequence of items in the Waste Hierarchy, and explain in particular, why landfill comes last, instead of e.g. incineration.
4. List the items in the end-of-life cost of a product, and explain how it is possible to take these into account in the product cost.
5. Explain how the European waste-to-energy policy is working and describe its advantages and disadvantages.

## Internet Resources

European commission
http://europa.eu.int/comm/environment/waste/strategy.htm

International Solid Waste Association
http://www.iswa.org/

Resource Recovery Forum,
http://www.resourcesnotwaste.org

Chartered Institution of Wastes Management, IWMA, UK
http://www.iwm.co.uk/

The Air & Waste Management Association,
A&WMA, International
http://www.awma.org/

Waste Management, Inc.
Comprehensive waste and environmental services, USA
http://www.wm.com/

Environmental Protection Agency, USA
http://www.epa.gov/seahome/hwaste.html

Purdue University Household Waste Management software
http://www.purdue.edu/dp/envirosoft/housewaste/src/title.htm

Keep Baltic Tidy (in swedish)
http://www.hsr.se/sa/node.asp?node=1110

The Global Marine Litter Information Gateway
http://marine-litter.gpa.unep.org

The Global Marine Oil Pollution Information Gateway
http://oils.gpa.unep.org

# 11 Introducing Life Cycle Assessment in Companies

## 11.1 Conditions for LCA Analysis

### 11.1.1 Introducing Life Cycle Thinking

In this chapter we will describe how to set up an LCA analysis. A general overview is given of the constraints in this process, and how to deal with problems one may encounter. We will also explain how to develop an LCA course project to be used in educational workshops.

By and large the art of setting up an LCA analyses in practice is to specify the right tool for the right decision, and in the long-term to ensure that decision-makers routinely incorporate *life cycle thinking* into their work.

An important objective is to make both the practice and the results of Life Cycle Assessments more generally accessible and intelligible, so that life cycle approaches become a central part of environmental analysis and debate. An important part of this is to make LCA compatible with other decision-support tools to achieve a wider acceptance of life cycle thinking in all parts of society [LCANET, 1996].

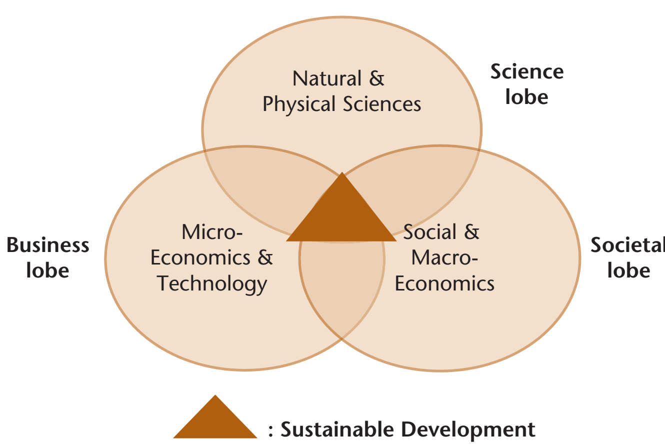



**Figure 11.1** *Conceptual framework for decision-making [LCANET, 1996].*

### 11.1.2 LCA should Support Sustainable Development

It is important that the LCA work support sustainable development. In practice this is approached very differently in different sectors of society and in different *subcultures*. We may distinguish between three different perspectives [WCED, 1987 and Clift, 1995]:

- Natural and physical sciences, including ecology and thermodynamics: the physical laws and relationships that shape ecosystems. Perspectives in this area are described as *scientific*.
- Micro-economics and technology: the economic relationships, structures and products that shape business systems. Perspectives in this area can be described as *business-oriented*.

**In this Chapter**

- Social issues and macro-economics: the social structures and issues that shape society, reflecting peoples' values. Perspectives in this area are described as *societal*.

These three areas can be envisaged as overlapping lobes as in Figure 11.1. The area in which all three lobes overlap (the dark/green hatched area), where all three broad sets of constraints are satisfied, represents the area in which decisions promote sustainable development. In other words, sustainable development is not possible without consideration of all three areas.

Different decision-makers and other stakeholders start from different points in the diagram, and may move to different locations in each lobe during the decision-making process. Sometimes typical trajectories can be envisaged for decision-making processes, and Figure 11.2 illustrates four examples.

Trajectory A describes the pathway for a purely scientific decision: the decision-maker begins with a consideration of ecological and thermodynamic constraints, and may modify his/her decision to take account of business and social contexts to arrive at a decision that promotes sustainable development. An example is the burning of waste materials as an alternative fuel source.

Trajectory B may describe the decision-making trajectory for a technological company providing goods to other companies, but not dealing directly with individual consumers. Its baseline is to make a profit, and so the decision-making process begins with business considerations in the Business lobe, and then progresses into the overlap with the Social lobe as it takes account of customer and societal expectations about its products. It may then consider the environmental implications of its products, and thus move into the area in which decision-making contributes towards sustainable development. Alternatively, a company that provides products or services directly to

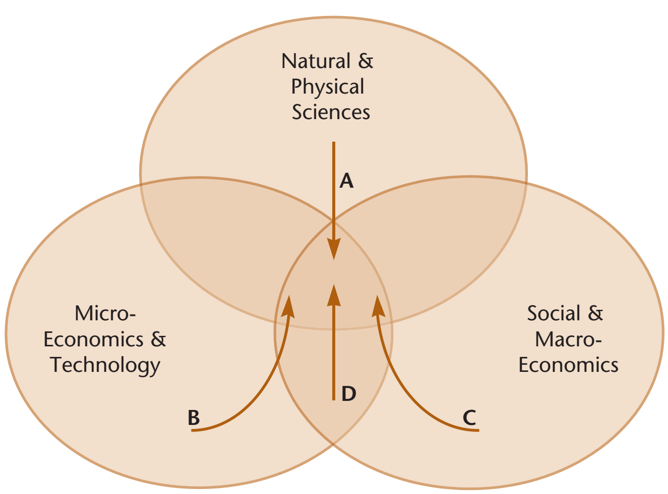



**Figure 11.2** *Trajectories of decision-making [LCANET, 1997].*

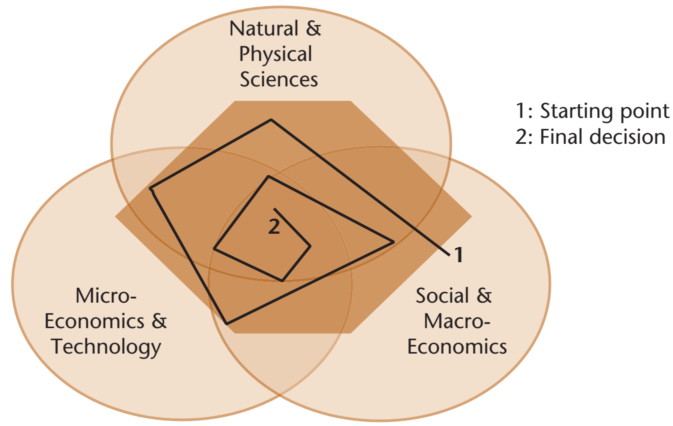



**Figure 11.3** *Example of a decision space in the conceptual framework.*

consumers might actually start in the area of overlap between the Business and Social lobes, undertaking market analysis as the first stage in new product development (trajectory D).

Trajectory C may be typical of some public bodies: they begin to formulate policy on the basis of societal expectations and concerns, and progressively take account of business and environmental concerns in order to make decisions in the sustainable development area.

In practice, decisions usually involve an iterative process of considering different factors and modifying alternatives to arrive at a final decision. Therefore, rather than describing single trajectories for a decision, it can be useful to envisage a *decision space*; an example is shown in Figure 11.3. It describes the boundaries (or constraints) on factors taken into account throughout the decision-making process, and is shaped by the views of those involved in decision-making as well as the procedural characteristics of the process. In this figure, defined starting and finishing points are identified within the decision space, relevant to this example.

### 11.1.3 Supporting Decision-making

Figures 11.1, 11.2 and 11.3 describe the overall decision-making process. However, an LCA analysis is primarily devised to support life cycle management in decision-making. Therefore, below we will focuses on the Scientific lobe of the diagram and its overlap with the two other lobes. This should not be construed as a rejection of the relevance of the other two lobes: indeed, "green" products that do not sell cannot deliver any environmental benefits, and so economic feasibility and societal acceptance must be essential components of the decision.

In the overlap area between the Scientific lobe and the other two lobes, a range of approaches have been developed to aid decision-making that leads to sustainable development, and a number of these are described in the SETAC CRP Working Group paper [De Smet et al., 1996]. The different components that contribute to decision-making in this lobe are shown in Figure 11.4 and described below.

Goals set the overall direction for decision-making. Progress towards a decision, in the first instance, is guided by the goals and requirements of the decision-making organisation. Goals may include the *Safeguard Subjects* of the EPS approach, or be expressed through the Environmental Policies of organisations, regions or countries.

### 11.1.4 Four Requirements

Four generic requirements are necessary for environmental management:

- Human and environmental safety.
- Regulatory compliance.
- Efficient use of resources and waste management.
- Addressing societal expectations and concerns.

These should be regarded as requirements that must be met in all environmental management decisions. Some of the requirements can be interpreted as being in the overlap regions of Figure 11.1. The importance attached to each one may change depending upon the decision and the stakeholders involved in the decision-making process.

## 11.2 The Decision-making Process

### 11.2.1 Tools and Methods Used for Decision Making

There are important differences between practical approaches based on tools or methods. Decisions are reached via an iterative process involving various components, as outlined below, and resulting in action. They may be guided by concepts such

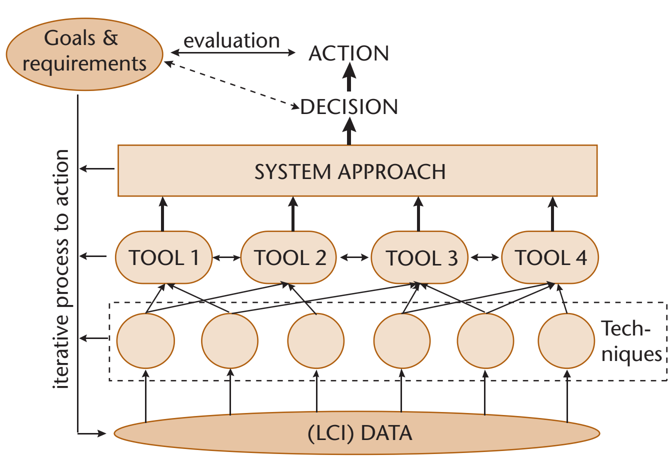



**Figure 11.4** *Components of environmental decision-making.*

as Industrial Ecology, Cleaner Technology, Waste Minimisation, and Dematerialisation. All environmental management decisions should fulfil the requirements, and result in progress towards the goals.

LCA *techniques* are considered as prescribed *methods* of obtaining data, processing and presenting information. Examples include dispersion modelling, energy balances and material balances. An LCA technique may supply information to a variety of different *tools* and any one tool may require information from more than one technique.

Tools can be described as means of combining information in a form which can be used in decision-making processes. Generally, no single specific tool can provide all the *information required for making decisions*. Therefore, combinations of tools are used in decision-making. The choice of these tools and the integration of the results in itself constitute a process. One or more stakeholders will be involved in this process in order to define which tools are chosen, and indeed if other factors should be taken into consideration. Therefore, an LCA *analysis* can be described as: A way of using and integrating different tools with stakeholder expectations and other decision parameters to meet one or more of the requirements for a decision.

It is worth noting that tools can be standardised while this is not possible for decision-making processes. This is because the decision context determines which combination of tools is most appropriate, and how the output of these tools is used. However, it may be possible to develop guidelines for a specific LCA analysis to be used in different contexts.

The distinction between tools and analysis is useful because it helps to unravel some of the confusion that has arisen over use of approaches such as Environmental Impact Assessment (EIA), Environmental Risk Assessment (ERA) and LCA.

The implications for LCA of this distinction between tools and methods in practice are discussed in the next paragraph.

### 11.2.2 Distinguishing Between Tools and Methods

There are different ways in which LCA analyses are being developed and used in practice. On the one hand, there are LCA analyses developed to assess potential environmental impacts without regard to site-specific conditions, and in some cases using generic weighting factors. This is analogous to using LCA as a tool or technique. On the other hand, some practitioners argue that the more site-specific and subjective, evaluative components of an LCA analysis are crucial to the results and this should be recognised in the approach selected. This is analogous to using LCA as a system approach.

Both approaches have strengths and weaknesses. As a tool, LCA facilitates analysis, because all potential effect factors can be supplied in a "Do-It-Yourself LCA Manual". This requires practitioners to incorporate a defined set of impacts so that trade-offs between alternatives in the final decision are more transparent. It may give misleading results, however, because potential impacts are often different from actual impacts: local conditions may be critical in determining actual impacts. As a system, LCA may produce results that are more relevant to the decision under consideration, and which have greater acceptance. The emphasis has been on assessment of potential environmental effects, and relatively little attention has been paid to, for example, to find alternatives in the LCA or choice of weighting factors. Thus an argument can be made for further research into developing LCA based on a system approach.

It has already been discussed that stand-alone, comprehensive LCA product analysis is unlikely to be sufficient – or entirely appropriate – as a basis for environmental decision-making. Reasons include:

- Those making the decision may consider the environmental impacts assessed in LCA irrelevant to the decision. In fact, it is inherent in LCA that it will identify the interests of groups and individuals who are not party to the decision.
- The cost of undertaking a comprehensive LCA may outweigh its usefulness in the decision-making process.
- LCA does not consider the strategic context for decisions. Many decisions have relatively long-term implications (for example, waste incinerators may be constructed to operate for ten to fifteen years), and thus a decision at one point in time may mitigate against the introduction of future innovative alternatives with greater environmental benefits.
- LCA generally does not account for the wider implications of decisions, such as changes in the structure of industry sectors. (Although in theory this could be incorporated into LCA methodology by defining whether decisions cause incremental or step changes).

### 11.2.3 Product Development Process

A general diagram representing product development is shown in Figure 11.5. It is presented here to illustrate an example of how various tools and elements may be integrated in a business process, such as product development. The various tools and elements that are used throughout different stages of this process (Box 3.1) broadly incorporate the ideas represented in Figure 11.4. This approach is derived from the concept of Design for the Environment (DfE), [Kortman et al., 1995], (Chapter 1).

### 11.2.4 Involvement of Stakeholders

By stakeholder we generally mean those with a direct interest in the decision, that is those who are responsible for financing it, those who are directly affected by it (for example, by emissions, noise, vibration, etc.), and those who are responsible for its implementation. A stakeholder is defined as: "Some-

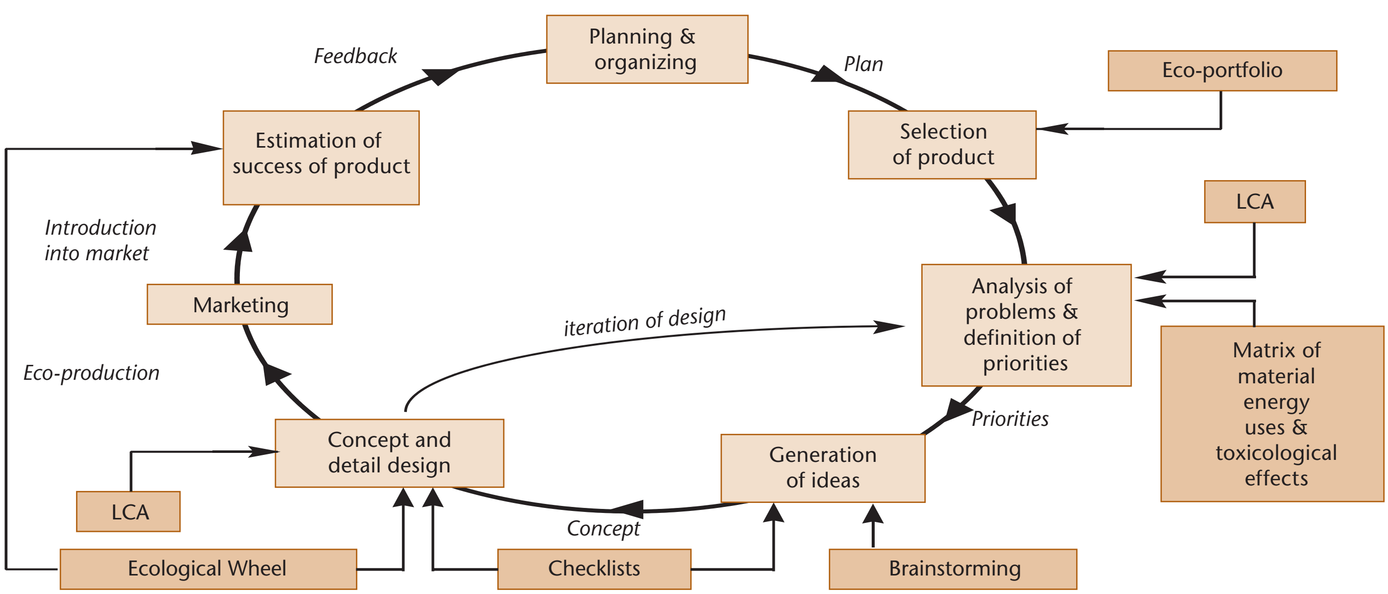



**Figure 11.5** *Product development incorporating various methods, tools and techniques.*

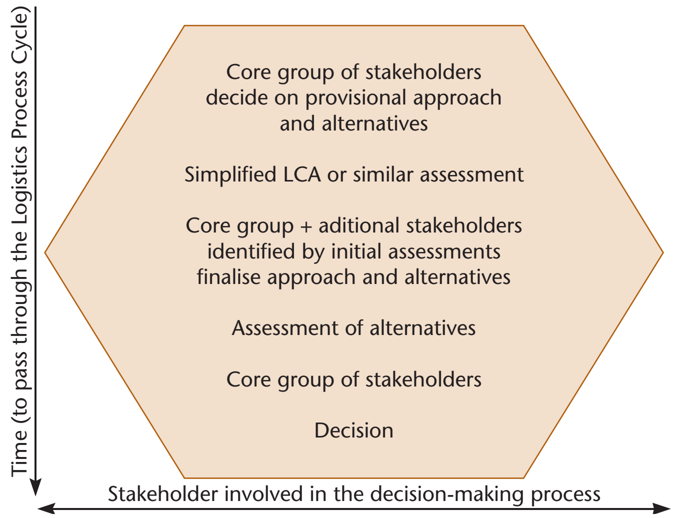



**Figure 11.6** *Involvement of stakeholders at different stages in a decision-making process.*

one with a legitimate interest in the decision". *Someone* may be an organisation or individual, and *legitimate* is defined as someone who may be affected by the decision. People or organisations without a legitimate interest in the decision are considered to be *interested parties*. In principle the interests of all stakeholders should be represented in the LCA analysis, whereas interested parties should be kept informed.

If LCA is used in the decision-making process (Figure 11.6), there is a potential role for stakeholders during Goal Definition and Scope, Impact Assessment, and Improvement Assessment. At all these stages, subjective decisions are taken that affect the results of the LCA and therefore the decision. In theory, it may be argued that all stakeholders should be involved in decisions taken during these stages, and that all their concerns should be addressed. In reality, this is impossible due to limits on time and money. Furthermore, because of the extended system described by LCA, some actual or potential stakeholders will be impossible to identify and involve as individuals. It may then be appropriate for their concerns to be represented by others more directly involved in the process.

Possible methods and procedures for stakeholders involvement include citizen advisory committees, consensus building and mediation. Interested parties would be kept informed of progress towards a decision. The implication is that LCA analysis can be simplified as part of the decision-making process by eliminating aspects not relevant to any of the stakeholders. However, exactly who should be involved in this process of simplification and, indeed, who should decide who is involved are questions that require more in-depth research.

It may be argued that these citizens also focus on issues in geographically distant areas, such as preservation of rainforests and pandas. This can be interpreted as a display of altruism. However, some economists argue that these concerns should be perceived as issues that also deliver benefits to the citizens in terms of their so-called existence value [Cekanavicius and Semeniene, 2003].

### 11.2.5 LCA for Raising Awareness or for Decision-making

It is worth noting that there is a tension here between the usefulness of LCA in raising awareness about environmental impacts irrespective of their geographical location, and its incorporation into decision-making processes. Some, decision-making processes focus on minimising impacts that occur "closer to home". For example, a region or country will tend to make decisions that deliver benefits to its citizens and be less concerned about any negative consequences of these decisions occurring outside its borders

Businesses are likely to make decisions that deliver shorter-term financial returns to the company and its shareholders rather than those that result in environmental benefits without a defined financial value in current economic systems. Therefore, there is a danger that recognition of LCA as a simplified system model, and legitimisation of simplified LCA analysis result in decision-makers excluding environmental impacts they consider irrelevant or that occur outside their geographical area of concern. In this way, the usefulness of LCA in providing an overall analysis of environmental impacts may be undermined. On the other hand, the selection of impacts of concern can also be interpreted as part of the valuation phase, although the valuation feeds into the process at an earlier

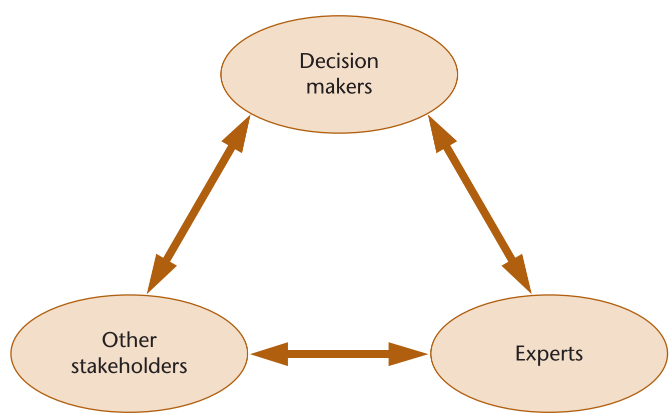



**Figure 11.7** *Participants in modelling as part of integrated environmental assessment.*

stage than conceived in the SETAC Code of Practice [SETAC, 1993].

Workshop participants built on this idea to include decision-makers within the model development (Figure 11.7).

Based on the general starting points, the objectives for a manageable LCA analysis are:

- A clear and comprehensive specification of the system functionality.
- A determination of the design, realisation, use and phase-out of the intended system.
- An indication all logistical processes, products and actors.

## 11.3 Introducing LCA Projects in Industry

### 11.3.1 Starting an LCA Project

An LCA project in industry is most often initiated by someone who commissions the project. The commissioner wants it to be done and has an idea of its goal. This is often a middle-level manager without specific LCA expertise. The LCA analyst, with some expertise, will scope the project, and in fact say if it is at all possible to conduct, or quite often rephrase it to make it possible. Sometimes a technology student may have that role and conduct much of the work as a master's theses or early experience at a company.

Most LCA projects are comparative: very few are explorative. Then exactly what to compare is an important decision to be taken by the analyst. If complex equipment is analysed, perhaps it is necessary to look at a component of the total system rather than the whole to get started. In the case below when two materials, viscose and polypropylene, were to be compared, the analyst's decision was to look at a product (diaper) where either of the two materials were used, and thus end up with a classical comparative LCA study.

The purpose of an LCA study varies. Sometimes it is just to learn about a specific product or material, as in the Akzo Nobel case. Often the results are used in reports and marketing or in green labelling of products. Very often the results and intentions behind a project are informal, never stated in an official document. Regularly the outcomes are unpredicted, with results and consequences that are not foreseen.

Among concrete outcomes are:

- Redesign of products.
- Change of materials in products.
- Find a different provider of materials.
- Change packaging of products.
- Change production processes.
- Change logistics.

### Box 11.1 Setting Up an LCA Course Project

For an LCA course project it is recommended to undertake a simplified LCA analysis to identify "hot spots" in the life cycles under consideration. A simplified LCA is defined by the SETAC-Europe LCA Working Group on Screening and Streamlining of LCA in their report entitled "Simplifying LCA: Just a Cut" [Christiansen, 1997]. It consists of a three step process involving:

- Screening identification of elements that can be omitted or assessed by other tools, i.e. hot spots, or identifying where generic data can be used.
- Simplifying development of the simplified analysis.
- Reliability assessment ensuring results are reliable enough to justify the conclusion.

This can be represented as the process described in Figure 11.8.

Stage 1 begins with a simplified LCA study considering the whole life cycle. This identifies "hot spots" which should be considered in further detail, using appropriate site-specific methods. At Stage 2; i.e. the simplified LCA identifies processes where LCA must articulate with other tools such as EIA and ERA. As a result, the final process involves a consideration of both generalised, potential effects (which may be evaluated on a site-dependent basis) and truly site-specific impacts (Stage 3), examined using a range of tools assembled into the overall process. Used in this way, LCA may identify some salient site-specific issues, but there may well be other site-specific problems not revealed by the LCA.

Knowledge about the practical guidelines and the methods, as discussed above, is essential to understand these cases and work out an LCA analysis during the course project.

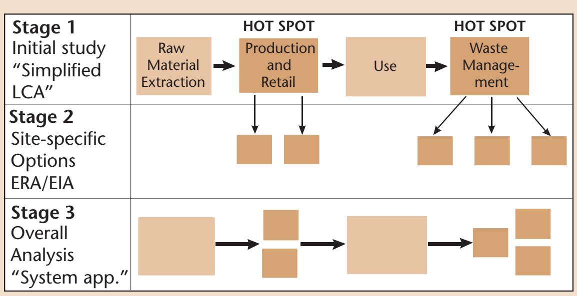



**Figure 11.8** *Process integrating LCA with site-specific methods.*

## LCA projects

### Example 1: Television set, Bang & Olufsen, Denmark.

Bang & Olufsen, recognised producer of high quality audio equipment, asked in 1997 for an LCA study of its television set. The study was carried out by EDIP/UMIP (Environmental Development of Industrial Products, in Danish UMIP) method. The results demonstrated that 92% of the environmental load was due to energy consumption during the use phase. Energy was produced using crude oil, natural gas, brown coal, and uranium, which are all connected to pollution ($SO_x$, $NO_x$, CO, heavy metals) and emission of carbon dioxide. Electricity use during operation and stand-by was thus defined as the most critical issue. The company was at the time able to decreased electricity use by 7% by product development.

The establishment of the EDIP method was followed by a life cycle assessment information centre in 2002. The LCA Center Denmark offers a wide range of services to companies and institutions, and participate as partners in international projects related to product oriented environmental approaches or integrated product policy (IPP), info@lca-center.dk [Wenzel et al., 1997].

*http://www.bang-olufsen.com*

### Example 2: Viscose fibres, Akzo Nobel Surfactants, USA.

At the time (early 1990s) viscose fibres, a wood-based fibre, was considered environmentally not good because of emission of $CS_2$ during its production. Many products were produced with either viscose or polypropylene synthetic fibres. The production manager of the viscose fibres were interested in environmental management and agreed with a newly employed technology student that he conducted an LCA analysis of a product in which two diapers were compared, with each of the two materials. Here polypropylene had 96% of the market and viscose the rest. The time for the project was about 20% of working hours over 6 months.

The results turned out to be very interesting. The difference in environmental load between the two materials was small. The impact of $CS_2$ emissions was not large, and not the dominating one in the profile. A further analysis of the roughly 100 steps in the viscose life cycle showed that only a handful were of any significance, and none of these were at the Akzo Nobel plant. For example the transportation of wood from the forest and emissions from trucks, were among the largest, due to $NO_x$ emissions, which nobody knew before. [Baumann and Tillman, 2004].

*http://www.surface.akzonobel.com*

### Example 3: Beer, Brewery, Germany.

The life cycle of beer was analysed using LCA methods for an eco-beer, where the company wanted to improve the environmental profile even more. The several changes made included the use of organically grown barley, wheat and hops, to reduce the impact of fertiliser and pesticides in the supply chain. Further fossil energy used in production was replaced, and the amount of water in production was lowered by 40% and the amount of waste by 50%.

Two different kinds of packaging for the beer were compared by LCA. A returnable box made of polypropylene and polystyrene, and a non-returnable one of cardboard, polyethylene and with a wooden frame. The study showed that the returnable packaging was superior after 8 rounds. It further proved that the paint on the packaging was emitting heavy metals; it was replaced.

The company concluded that a full LCA, recommended in the ISO standard, was rarely used in practical work, as a screening analysis was more interesting. To increase the more wide spread use of LCA would require more easily available LCI databases and LCA software. [Scholl and Nisius, 1998].

### Example 4: Documentation, Ericsson, Sweden.

The LCA project at Ericsson concerned the documentation required for a business telephone switching exchange. The documentation described all details in how to set up and operate the exchange. This was traditionally a series of 80 ring binders. The documentation manager wanted to exchange them for e.g. an electronic medium but could not convince the production managers with economic or other arguments. However environmental arguments were more interesting due to the environmental policy of the company. An LCA project started in cooperation with CPM, (Center for Environmental Assessment of Product and Material Systems) a university-industry cooperative centre. The LCA analyst was a student running the study as his diploma thesis. He spent about two months collecting data and two months doing the calculations. The study was basically done according to the ISO 14040 standard. Not surprisingly the result showed that using a CD caused about 700 times less environmental impact than using the ring binders. A large part of the impact was due to transportation (by air) of the binders to customers. An additional benefit of the study was that a complete overview of the documentation system was produced and there was now reason to modernise it. LCA work was established at Ericsson after this initial project. [Baumann and Tillman, 2004].

*http://www.ericsson.com*

The most important non-physical outcomes are the learning process, the reports (messages) to the market or the customers, and the better understanding of a complex system of production. A key result is often the complete overview of the often complex system of a product, which LCA always provides. This includes the supply chain, production, marketing, use and wasting of a product. This overview is useful in many situations, not least economic.

Many studies, however, do not end up as full-scale LCAs, all the way to weighting. It is more common to be satisfied with the results of the inventory analysis or partial results. Neither is it very common that the ISO 14040 standard is followed all the way.

### 11.3.2 Institutionalising LCA

LCA in most companies is not well established. To start it, get some experience, and finally create an organisation to deal with LCA on a more regular basis is a process that often takes years. Such a process will not start unless some individuals see the regular need for LCA and start the process.

Often the company then cooperates with LCA study centres or national resources created by e.g. technical universities or branch organisations. Above we have mentioned one Danish and one Swedish centre. These develop LCA methodology, have access to or create their own databases, and of course have considerable experience.

There are several different incentives to establish an LCA group or activity. Outside pressure is one. If other companies in the same field are doing LCA, others will often follow, as in the car industry. LCA is also introduced to combat a bad environmental reputation, as in the chemical industry. Companies which are working on improving their environmental profile in other ways, such as green labelling of products, or using ecodesign, are also more easily adapting LCA as one more tool to address their environmental concerns.

### 11.3.3 LCA Today and in the Future

In the early 21$^{st}$ century LCA is fairly well established. One report from 2000 (Frankl and Rubik) mentions that between 5% and 40% of industry uses LCA, depending on branch and country. The figure is expected to increase as knowledge develops, data becomes more accessible and political support mounts. The process is supported within the European Union's IPP (Integrated Product Policy) Directive. It is stressed that there are several good reasons why a business may benefit from getting involved in LCA or LCT (Life Cycle Thinking), such as identifying potential savings, compliance with environmental legislation and easing supply chain pressure.

In mid-2005 the Commission established the European Platform on Life Cycle Assessment project (See Internet Resources, *NetReg Environment Agency*). Sectors included in this three-year pilot project are: electronic and electrical equipment; metalworking; urban furniture (lamp posts, letter boxes etc.); office use; hotels; wood products; and textiles. Small businesses (SMEs) are able to find information and tools to support the undertaking of LCA for their own products and services on a Website called ecosmes (http://www.ecosmes.net/). This brings LCA within reach for small businesses for the first time.

The project aims to promote and support more reliable LCA studies by providing:

- Reference data and recommended methods for LCA, including core Life Cycle Inventory (LCI) data of European business associations, including data on energy, transport and waste management.
- Life Cycle Impact Assessment (LCIA) factors for estimating the potential impacts on resource consumption, the environment and human health.
- Handbook of Technical Guidance Documents for LCA, to provide consensus on best practice.

This recent information from the web site of the Commission will certainly promote the wide use of LCA in the near future.

## Study Questions

1. What are the three perspectives with regard to LCT?
2. Describe an iterative decision-making process.
3. Describe a step-by-step approach for an LCA.
4. Describe how to support a middle-level manager by setting-up an LCA
5. What are essential elements in a LCA business case?

## Abbreviations

| | |
|---|---|
| EIA | Environmental Impact Assessment. |
| ERA | Environmental Risk Assessment. |
| IPP | Integrated Product Policy. |
| LCT | Life Cycle Thinking. |

## Internet Resources

NetRegs – Life Cycle Assessment and Integrated Product Policy

http://www.netregs.gov.uk/netregs/275207/663774/?lang=_e

EcoSMEs – Services for Green Products Project
(financed by the European Commission)

http://www.ecosmes.net/

The Society of Environmental Toxicology and Chemistry (SETAC)

http://www.setac.org/

NetRegs – plain language guidance for
business on environmental legislation

http://www.netregs.gov.uk/netregs/?version=1&lang=_e

Institute of Environmental Sciences (CML) Department of Industrial Ecology. Leiden University. LCANET was a project conducted by CML.

http://www.leidenuniv.nl/cml/ssp/

The Centre for Environmental Strategy (CES),
University of Surrey, UK

http://www.surrey.ac.uk/eng/ces/staff/acad.htm

# 12 LCA Analysis of Systems

## 12.1 How to Use LCA for Systems

### 12.1.1 LCA for Products or Systems

Above we have seen how LCA can be used to assess the potential environmental impacts of products. Here LCA is used as a tool. As a tool, LCA analysis is easier since all factors of a potential environmental effect can be evaluated in a "Do-It-Yourself LCA Manual". Practitioners may incorporate a defined set of impacts so that trade-offs between alternatives in the final decision are more transparent. It may yield misleading results, however, because potential impacts are often different from actual impacts. In some situations a more site-specific and subjective evaluation of LCA is crucial to the results.

This is the case when LCA is used to evaluate more complex situations than the production, use and scrapping of single products. It is especially interesting to use life cycle assessments for evaluating systems. By systems we will understand processes where many different "products" are used together to make possible a more complex operation. This could be to run train traffic, to extract oil from the sea bed, or to build and run a ship. Thus the train traffic requires that there are rails, the trains themselves, the stations, and the personnel. Of course the system boundaries can be placed relatively close to or far away from the core of such a system.

When used for the analysis of systems, LCA may produce results that are considered more relevant to decision makers. It may be possible to assess the environmental consequences of specified functions, or to calculate the environmental consequences for the amount of money spent. We may in this way have an opportunity to minimise the environmental impact per cost. We may also compare two different strategies to execute a certain function. For example the function of transporting a person from one place to another may be analysed, and train, bus and private car could be compared.

In this chapter the LCA analysis of systems will be introduced, developed and tested to support Life Cycle Management (LCM) of capital assets [Stavenuiter, 2002]. Capital assets are the physical components of systems, such as rails, trains, and station buildings in a railway system.

### 12.1.2 LCA Analysis Method on Systems

The LCA analysis method of systems introduced here is based on the so-called integrated Logistics Process Cycle (LPC). This is composed of eight different parts, as illustrated in Figure 12.1.

As a starting point it is assumed that the process is directly related to the installations. These are the components which make up the system, such as infrastructure e.g. railways, or vehicles e.g. boats, or parts of a production chain such as machinery, etc., that is, the capital assets of the system. These all have separate, well-defined functions.

For each installation there is an actor, or group of actors, responsible. An actor could be the design department, the workshop, the specialised contractor and so on. In order to

**In this Chapter**

meet the required functions the systems must have certain logistical products and services. These could be design, production, installation, testing and maintenance.

As systems become more complex, installations become more complicated. This means that more logistical control, products and services are necessary, such as documentation, instruction, training, configuration management, etc.

Thus the Logistics Process Cycle of the system contains the following four material components:

- Resources.
- Actors.
- Activities.
- Products and services.

In addition to these the cycle has four logistical components:

- A budget to finance the resources.
- An operational need to justify the budget.
- Installation performance.
- System functionality.

To provide the required products and services on schedule, the system demands well-tuned logistical activities for the whole life cycle of the system. Logistical activities could be designing, production, maintenance, etc.

The system is developed to fulfil a certain operational need, and is provided with a (financial) budget used to acquire human and material resources. These become logistical actors when they have been either trained (people) or installed (equipment/material). With the logistical actors it is possible to perform logistic activities. These activities provide the products and services that are necessary to achieve the required installation performances. When this happens the integrated LPC is closed (Figure 12.2).

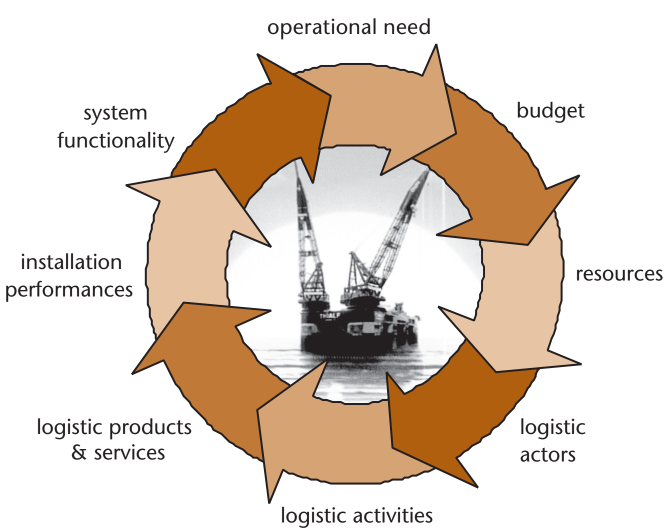



**Figure 12.1** *The Logistics Process Cycle around the offshore crane ship "Balder".*

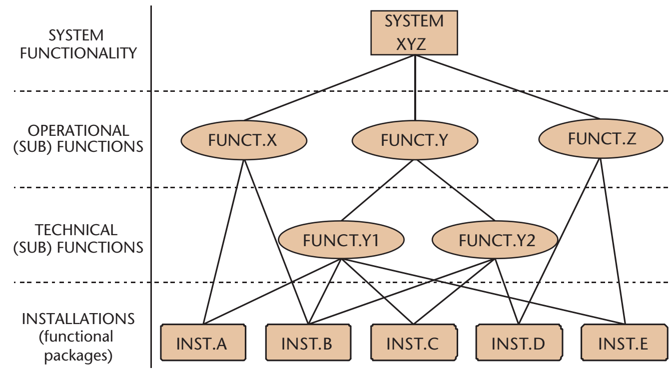



**Figure 12.2** *The functional material part breakdown.*

### 12.1.3 Life Cycle Management, LCM

An overall management of the entire logistics cycle is necessary to maximize performance. When this is done in a life cycle perspective it is called Life Cycle Management (LCM). It is provided by a LCM team.

The Logistics Process Cycle (LPC) in Figure 12.4 is seen as an "up and running" logistics process broken down into eight entities. When the asset life cycle is reviewed, from conception to phase-out, the LPC should be read in two directions. For design, adjustment and evaluation it turns anti-clockwise. For production, operations and phase-out, it turns clockwise.

The dimension "time" is not considered yet. It is assumed that balancing the LPC will be a continuous activity throughout the asset life cycle.

To specify the necessary logistic (management) information, knowledge and skills, an analysis should be done for all phases of the life cycle. To approximate the different phases, the LCP analyses are related to the four main LCM objectives, as illustrated in Figures 12.4a-e.

To provide each entity of the LPC with adequate management and control information, we will define below its contribution as manageable objectives/specifications per life cycle phase. For each phase the analysis will start from the operational need.

In practice the module will provide the qualitative content of the LCM data set. The intended information set should be sufficient to establish the basic LCM plan and organisation structure for the management and support of the system during its life cycle.

To keep the LCA analysis of systems manageable, a criticality analysis should be performed first, because it is assumed that not all products and services will have a significant impact. Normally the criteria to determine the critical products and/or services are based on expert opinion in combination with relevant data more and more freely available from huge LCI databases, as described in Chapter 8.

## 12.2 Logistic Process (Life) Cycles Analysis

### 12.2.1 A Four-step Procedure for Analysis of Systems

A general LPC analysis has been done to provide a basic analytic framework for any (technical) system. The aim has been to unearth the necessary logistic means for each LPC element, beginning with the operational need. The basic results of the analyses are given per main objectives in Tables 12.1a-d.

To determine the overall environmental impact of the logistical products and services analysed throughout the life cycle of the system, the Eco-Indicator 95/99 approach is used. In line with the Eco-indicator approach the Distance-to-Target weighting method is used to assess an overall Eco-Indicator Value for each product or services which has been analysed. Putting this in a spreadsheet gives the opportunity to determine the overall environmental impact per installation and system seen over the entire life cycle.

It is assumed that balancing the LPC will be a continuous activity during the system life cycle. To specify the necessary logistical (management) information, knowledge and skills, an analysis should be made for all life cycle phases. The four phases to be discussed are:

**Figure 12.3 LCA of systems.** *An oil platform is a complicated system, consisting of thousands of parts. The LCA of such a system may include the entire life cycle since the platform will be removed after the oil well is no longer productive. Photo: Norsk Hydro ASA.*

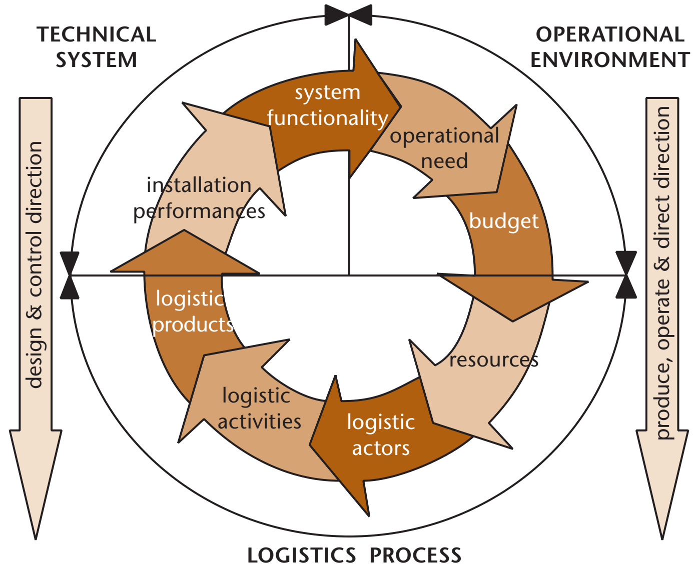



**Figure 12.4** *The Logistics Process Cycle related to the Asset Management Control Elements.*

- Planning the system – Specify System Functionality.
- Setting up the system – Acquire System Functionality.
- Running the system – Achieve Cost Effectiveness.
- Scrapping the system – Justify Phase-Out.

### 12.2.2 Planning the System

The planning of the systems is called the Specify System Functionality phase. It is the first objective in the LPC analysis of any system (Figure 12.5b). For each LPC phase, LCA analysis is composed of the eight distinct components described above, (Figure 12.1). Below we will discuss each one in turn.

In the planning phase the operational need should be expressed in operational requirements for making the system manageable. Because these requirements are the fundamentals for the entire system, it is very important to verify their accuracy and consistency [Stavenuiter, 2002].

For a capital asset, e.g. an oil platform, ships, aircraft, wind farms, or railways, it is assumed that the ILS Use Study is the most relevant. The aim of the Use Study is to identify and document the pertinent supportability factors related to the intended use of the new system, such as:

- Mobility requirements
- Deployment scenarios
- Mission frequency and duration
- Basing concepts
- Service life
- Interactions with other systems
- Human capabilities/limitations.

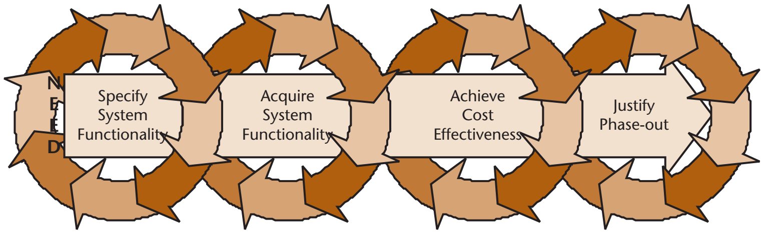



**Figure 12.5a** *The Logistics Process (Life) Cycles.*

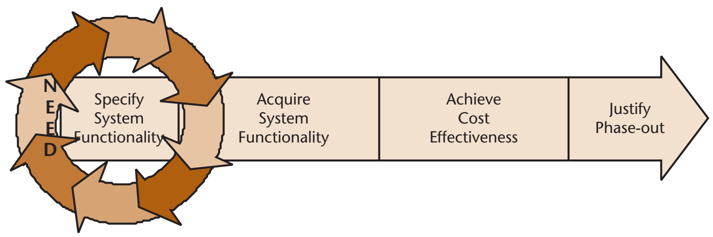



**Figure 12.5b** *The Logistics Process (life) Cycles. Specify System Functionality phase.*

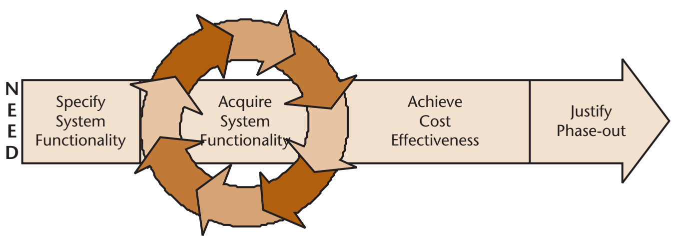



**Figure 12.5c** *The Logistics Process (Life) Cycles. Acquire System Functionality phase.*

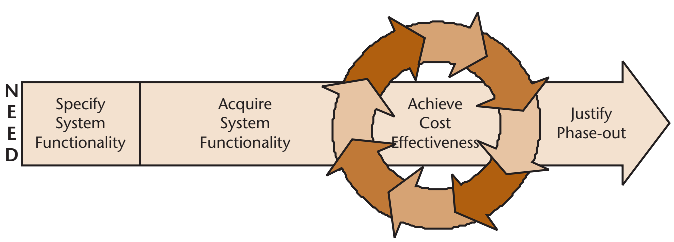



**Figure 12.5d** *The Logistics Process (life) Cycles. Achieve Cost Effectiveness phase.*

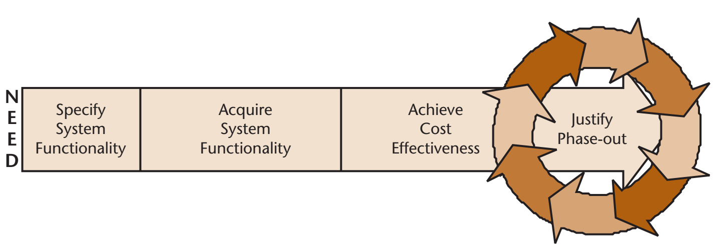



**Figure 12.5e** *The Logistics Process (Life) Cycles. Justify Phase-Out phase.*

The first problem in specifying the *Operational need* in this phase is to decide how good the performance should be, that is, the advisable or required "degree of perfection". Marcelis [1984] defined the term "degree of perfection" as a measurement of the perfection of the Logistical activities. He states that it is not always necessary to have the highest degree of perfection possible. Small organisations with relatively uncomplicated assets can be satisfied with a relatively low degree of perfection. In relation to LCA it seems that the degree of perfection also depends on what environmental protection is really needed and attainable when measured over the life cycle of an asset.

An iterative – repetitive – approach is used to determine the operational requirements. This means that the analysis phase starts with a rough specification of operational needs to be refined later in two or more LPC rounds. The Use Study specifications are taken as a starting point. It is essential to describe these specifications in concrete terms so that they can function as baseline requirements for test and evaluation purposes [Blanchard and Fabrycky, 1998].

The full support of *System functionality* is essential to ensure that the operational requirements can be fulfilled. According to the ILS/LSA method system functionality can be described by defining the system requirements and characteristics. This precisely detailed information should be provided by skilled system engineers using approved engineering methods and techniques [Blanchard and Fabrycky, 1998; Jones, 1995]. Here too, the degree of perfection and tailoring has to be taken into account.

The next step is to determine the *Installation performance*. This can be estimated on the basis of the role and impact of the installation in the functional system breakdown (Figure 12.2). Here the same approach can be applied for the installations as for the system definition and characteristics. Also here experienced design and maintenance engineers must provide the precisely detailed information needed. Again, the degree of perfection and the tailoring approach are of importance.

The installation performance, defined in relation to the LCM objective "specify the system functionality", corresponds to the *Logistical products documentation and services* to support system activities. Depending on the circumstances and system complexity the products and services can be determined and specified. The physical products and services are based on the specified information from the first two elements.

From this point the environmental impact is considered. Environmentally critical products or services must be flagged and assessed for their criticality. The critical products or services can be analysed according to the Eco-Indicator method by using the information as described below.

The *Logistic actors* (production units, departments, contractors, etc.) can be found by looking not only at the organisation but at the entire industry. Special attention should be paid to the resource qualifications [Jones, 1995]. Because the compilation of actors can vary considerably per asset, the list of "types" of actors should only be seen as an example.

In the *Resources* element a search is carried out to determine possible resources, based on the logistic actor and product and services specifications. In this stage of the life cycle it should give an idea of whether the necessary resources are available and adequate.

In the *Budget and Environmental Impact element* the cost and environmental impact estimate is based on the insight gained so far. The accuracy of this will greatly depend on the available expertise and data.

In Table 12.1a are listed selected examples of a LPC short list for Specify System Functionality phase. In the context of the LCA analysis, each item of the LCP short list must be assigned to an Eco-Indicator Value to determine environmental impact of indicated products and services.

### 12.2.3 Setting Up the System

Once the system functionality has been specified we move into the setting-up or acquisition phase, called the Acquire System Functionality phase. Again all elements of the LPC will be analysed.

With the *operational need* finally specified for the use phase, it is reasonable to assume that it will remain the same from the first phase till the phase-out of the system. We thus assume that the previous specifications remain the same here.

The *system functionality* also remains the same for the same reason. The specified installation performance does not change for the same reason as for the operational need and can be adopted from the previous phase.

Now the *installation performance* should be carried out to "acquire system functionality". The major logistic products and services will consist of physical installations. Besides this, a large amount of equipment and activities necessary for the support of the installations have to be acquired. Depending on the circumstances and the complexity of the installations the types of products and services should be determined. The specified physical products and services are not only based on the information derived from the first two elements of this phase but also from the previous phase.

From this point on the environmental impact of critical products or services must be flagged and assessed. The critical products or services can be analysed according to the Eco-Indicator method by using the information as described below.

**Table 12.1a**
*Examples of LPC Short List: Specify System Functionality.*

| LPC Short List: Specify System Functionality | |
|---|---|
| Operational Need | Operational activities and functions (transport, navigation, etc).<br>Operating requirements, e.g.: speed, safety level, etc.<br>Missions per period and duration.<br>Reliability, availability and safety requirements.<br>Environmental requirements, hazardous materials/ waste. |
| System Functionality | Functional decomposition, interfaces and criteria.<br>Environmental conditions.<br>Maintenance plan.<br>Performance and physical characteristics.<br>Effectiveness requirements. |
| Installation Performance | Specific operational requirements.<br>Functional interfaces and criteria.<br>Environmental conditions.<br>Performance and physical characteristics.<br>Capability, reliability, availability, safety and risks, recyclability. |
| Logistical Products: | Advance system realisation planning (technical and organisational).<br>Operational and system requirements.<br>System specifications and design.<br>Functional and technical installation specifications.<br>Acquisition and quality assurance plan.<br>Contractor data requirements list.<br>Reliability, availability and maintainability plan.<br>Personnel and training plan.<br>Technical data and information systems plan.<br>Packaging, handling, storage and transportation plan.<br>Facilities plan. |
| Logistical Services: | Program/project management (LCM team).<br>Feasibility studies and bench marking.<br>Design to cost.<br>Cost calculations.<br>Risk management. |
| Logistical Activities | Resource planning and control.<br>Project management.<br>Utilization feed back.<br>Systems design and maintenance engineering.<br>Information, document and quality management.<br>Financial and commercial engineering.<br>Supply, facility and human resource policy/ management. |
| Logistical Actors | Project management department.<br>Design department.<br>Systems and maintenance engineering department.<br>Product data management centre.<br>Quality management department.<br>Personnel and supply department. |
| Resources | Manpower, energy, raw materials. |
| Budget and Environmental Impact | Euro/dollar.<br>Eco-Indicator Value. |

The *logistical activities* are determined by an analysis of the products and services. The next step can be carried out when it has been checked that there is an activity for every product. The logistical actors are determined by analysing the activities. The actors (production units or contractors) can be found by looking beyond the organisation to the entire industry. In this element the resource qualifications demand special attention [Jones, 1995].

In the *Resources* element the same approach will be carried out as in the first round. This means a search will be carried out, among the possible resources, based on the logistical actor specifications. This will give an idea of whether the available resources are adequate. Based on this analysis it can be estimated whether a specific effort is required to transform the resources in effective logistic actors e.g. coaching and training staff or tuning machinery. For these activities the precisely detailed need will be determined in the Program Module.

In the *Budget and Environmental Impact element* the cost and environmental impact estimate is based on the insight gained so far. Obviously the accuracy of this will greatly depend on the available expertise and data. In the context of the LCA analysis, the last column of the LCP short list is assigned to the Eco-indicator value.

In Table 12.1b selected examples of types of products and services for LPC short list for Acquire System Functionality phase are given. In the context of the LCA analysis, each item of the LCP short list must be assigned to the Eco-Indicator Value to determine the environmental impact of indicated products and services.

**Table 12.1b**
*Examples of LPC Short List: Acquire System Functionality.*

| **LPC Short List: Acquire System Functionality** | |
|---|---|
| Operational Need | As defined in the Specify System Functionality phase. |
| System Functionality | As defined in the Specify System Functionality phase. |
| Installation Performances | As defined in the Specify System Functionality phase. |
| Logistical Products: | Complete installations (system units).<br>Acquisition planning (technical and organisational).<br>Technical installation specifications.<br>Quality assurance program.<br>Life cycle cost calculations.<br>Reliability, availability and maintainability program.<br>Education and training program.<br>Technical data and information systems.<br>Maintenance and storage facilities. |
| Logistical Services: | Program/project management (LCM team).<br>Financial and contract management.<br>Production/construction management.<br>Risk and quality management.<br>Product data management. |
| Logistical Activities | Resource planning and control.<br>Project/program management and planning.<br>Systems (support), financial and maintenance engineering.<br>Utilisation feed back.<br>Commercial engineering.<br>Purchasing, production, training.<br>Risk and quality control.<br>Store, information, document and human resource management.<br>Facility management. |
| Logistical Actors | Project management department.<br>Operations representatives.<br>Detail design department.<br>Systems (support) and maintenance engineering department.<br>Product data management centre.<br>Quality management department.<br>Supply and facility and personnel department.<br>Manufacturers. |
| Resources | Manpower, energy, raw materials. |
| Budget and Environmental Impact | Euro/dollar.<br>Eco-Indicator Value. |

### 12.2.4 Running the System

The phase when the system is operating is called Achieve Cost Effectiveness, since it is expected that the system operations and maintenance (utilisation) will be performed with optimal cost-effectiveness. Again all elements of the LPC will be analysed.

The *operational need* has been specified for the utilisation phase. Therefore the previous specifications will be adopted as a baseline. In this case the specifications recognised in the first phase remain the same. During the utilisation phase it is possible that the policy of the operation will change. This could be a reason for adjusting the operational need.

To ensure that the *operational requirements* will be achieved, they have to be fully supported by the system functionality. According to the ILS approach, the baseline for the system functionality has been specified in the first round. In this phase the actual system functionality should be achieved and measured. This means that, besides the specified definitions, the real definitions can be determined. The real characteristics can also be determined, which means there is a baseline situation and an actual situation. The system adjustments, differences and the actual situation are qualified as important management information [Juran and Gryna, 1993] and therefore added to the specified system information of the previous phase.

**Table 12.1c**
*Examples of LPC Short List: Achieve Cost Effectiveness.*

| **LPC Short List: Achieve Cost-Effectiveness** | |
|---|---|
| Operational Need | As defined in the previous LPC analysis. |
| **System Functionality** | |
| System definition: | Functional decomposition (function/installation diagram).<br>Functional interfaces and criteria.<br>Environmental conditions.<br>Maintenance plan.<br>System adjustments (modifications). |
| System characteristics: | Performance and physical characteristics (actual and baseline).<br>Effectiveness requirements and actual performances. |
| **Installation Performance** | |
| Installation definition: | Specific operational requirements.<br>Functional interfaces and criteria.<br>Environmental conditions.<br>Maintenance concept.<br>Installation adjustments (modifications) and differences. |
| Installation characteristics: | Performance and physical characteristics (actual and baseline).<br>Capability, reliability, availability (actual and baseline).<br>Maintainability and recyclability (actual and baseline).<br>Safety and risks (actual and baseline).<br>Energy efficiency (actual and baseline). |
| Logistical Products: | Design synthesis and evaluation.<br>Functional and technical performance tests.<br>Cost-effectiveness- related data.<br>Engineering change proposals.<br>Operational, intermediate and depot inspections and repairs.<br>Data acquisition and information systems.<br>Up to date system management information (cost and performance).<br>Capacity/cost reservations and overviews. |
| Logistical Services: | Provision of test and support equipment.<br>Quality assurance program and audits.<br>Reliability, availability and maintainability program and adjustments.<br>Education and training.<br>Asset/system management (LCM team).<br>Product data management. |
| Logistical Activities | Resource planning and control.<br>Program management and planning.<br>Systems support, maintenance and financial engineering.<br>Operational and intermediate maintenance.<br>Purchasing, training.<br>Risk and quality control.<br>Product purchase control.<br>Store, information and document management.<br>Human resource policy and management.<br>Facility policy and management. |
| Logistical Actors | asset/system management department<br>operations representatives<br>systems support and maintenance engineering department<br>product data management centre<br>personnel and commerce department<br>supply, facility and quality management department<br>manufacturers<br>education centres (schools). |
| Resources | manpower, energy, raw materials |
| Budget and Environmental Impact | euro/dollar<br>Eco-Indicator Value |

The next step is to determine the actual *installation performance*. In order to achieve installation performance in relation to the LCM objective "achieve cost effectiveness" the installations have to be sufficiently available, reliable and capable of fulfilling the required functionality during operation periods. The logistical products and services will here consist of installation/system support such as maintenance and overhaul.

From this point on the environmental impact of critical products or services must be flagged and assessed as to their criticality according to the Eco-Indicator method.

In this phase too, the *logistical activities* are determined by analysing the products and services. When it has been checked that there is an activity for every product then the next step can be taken. The actors (production units or contractors), determined by analysing the activities, are found by not only looking at the operational and maintenance departments within the organisation but at the entire industry. In this element the quality specifications require special attention.

A search is carried out, among the possible *resources*, based on the logistical actor specifications. This gives an idea of whether the available resources are adequate. Based on this analysis the specific effort required to transform the resources into effective logistical actors can be estimated e.g. coaching and training personnel or tuning machinery. For these activities the precisely detailed needs will be determined in the program module.

In the *Budget and Environmental Impact element* the cost and environmental impact estimate is based on the insight gained so far. The accuracy of this will, of course, greatly depend on the available expertise and data.

In Table 12.1c selected examples of types of products and services for LPC short list for Achieve Cost Effectiveness

**Table 12.1d** *Examples of LPC Short List: Justify Phase-out.*

| **LPC Short List: Justify Phase-out** | |
|---|---|
| Operational Need | A specification for disposal of the system in the most cost-effective way. |
| System (Phase-out) Functionality<br><br>*To determine the exact possibilities in the market and in ways of disposal the following system information could be relevant for the LCM-team.* | General description.<br>Functional decomposition (function/ installation diagram).<br>Environmental conditions.<br>Actual system effectiveness.<br>Actual physical overall condition.<br>Disposal propositions. |
| Installation (Phase-out) Performance<br><br>*Per installation the following information list should be compiled.* | General description.<br>Environmental conditions.<br>Actual physical condition.<br>Actual capability, reliability, availability, testability, maintainability.<br>Actual safety, risks, energy efficiency and recyclability.<br>Disposal propositions. |
| Logistical Products:<br><br>*The following products and services could be relevant in achieving an optimally cost-effective disposal of either the total system or the separate installations.*<br><br>Logistical Services: | Functional and technical performance tests.<br>Complete technical data package.<br>Actual system/installation management information (cost and performance).<br>Disposal plans.<br>Trade contracts.<br>Capacity/cost reservations and overviews.<br><br>Project management (LCM team).<br>Contract, financial and product data management.<br>Risk management. |
| Logistical Activities<br><br>*In analysis of the logistic products and services the following activities are recognised.* | Resource planning and control.<br>Project and planning management.<br>Systems (support), financial, commercial and maintenance engineering.<br>Risk control.<br>Information and document management. |
| Logistical Actors<br><br>*Based on the activities the following "types" of actors can be stipulated.* | Project management department.<br>Systems (support) and maintenance engineering department.<br>Product data management centre.<br>Accountancy and quality management department.<br>Commerce, personnel, supply and facility department.<br>Manufacturers. |
| Resources | Manpower, energy, raw materials. |
| Budget and Environmental Impact | Euro/dollar.<br>Eco-Indicator Value. |

**Figure 12.6 An Environmental Impact Assessment of a hydro-power plant.** *This EIA will consider the effects not only on the immediate surrounding but also on the river up- and downstream. The impacts considered will include ecological ones, e.g. biodiversity in the river stream; social ones, the consequences for those living along the river; and resource use impacts, e.g. the replacement of electricity produced from fossils with renewable energy. Photo: Vattenfall/ Hans Blomberg.*

phase are given. For the LCA analysis, each item must be assigned to the Eco-Indicator Value to determine environmental impact of indicated products and services.

## 12.2.5 Scrapping the System

The end phase of the system operation is to scrap the system, called system *decommissioning*, or *phase-out*. Here the question of recycling or disposal of material no longer required in the operational inventory is poorly covered in the literature. According to Blanchard [1992] it is common practice to address the design and development of a system and the subsequent operation of that system, whereas the phase-out and subsequent disposition of the system are often inadequately considered until the time arrives to do something about it. For this reason the phase-out has been integrated in the system specification phase.

In the phase-out period the *operational need* becomes a specification for getting rid of the system in the most cost-effective way. Depending on several factors this can be done by re-use, disposal of the components or recycling the material.

To ensure that the phase-out requirements will be achieved, they must be supported by the *system functionality*. According to the LCA method, the baseline for the system phase-out has been specified in the first round. Besides the specified targets, the actual figures also become available in this phase. The final result of this round should be the disposal of the system in a justifiable manner. To determine the exact possibilities in the

## Box 12.1 Environmental Impact Assessment

**Environmental Impact Assessment**
Assessing the impact of systems, such as railroads, factories, power plants etc is in this chapter approached from a life cycle perspective; life cycle management of such an installation is described. However the life cycle assessment technique for this task is complicated and not so often applied. Still it is very important to assess, as well as possible, the environmental and other consequences of a new installation. This is normally done through an Environmental Impact Assessment, EIA. The EIA is required by national legislation, as well as in the EU Directive on EIA, to serve as a basic document for deciding on a permit (license) for the construction and use of an installation. In short "Environmental assessment is a procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made" (Web site of the EU commission). The EIA Directive on Environmental Impact Assessment of the effects of projects on the environment was introduced by the Commission in 1985 and was amended in 1997.

**Different legal instruments and life cycle phases**
An EIA of an infrastructure such as a road, bridge or tunnel is mostly concerned with the construction itself, not so much the use phase. In the case of an industrial plant, or say an airport, not only the construction, but even more so the use phase, the functioning of the plant, and the air traffic for the airport, is carefully assessed in an EIA. An assessment of the scrapping, the disassembly, of the installation is normally not requested. Although an oil platform, illustrating LCA of systems in this chapter, obviously should be removed after the oil well is emptied, most infrastructures stay for many years perhaps hundreds of years. Still we should note that closing of such installations is done regularly and often leads to large costs. Thus clean-up of "brown fields", polluted old industrial sites, is an increasingly large cost for both the private sector and public.

The legal requirements vary between countries and procedures. The EIA Directive is just one such instrument. Thus permits for industrial plants are most often based on an IPPC (Integrated Pollution Prevention and Control) Directive license, which includes a review of all environmental impacts of running the plant. For plans, programmes and policies an SEA, Strategic Environmental Assessment, is made based on an EU Directive adopted in 2000, mostly used for transport infrastructure plans. There are also requirements regarding trans-border effects of new installations, such as a hydropower plant, which may influence a river upstream or downstream into another country.

**Public participation and access to information**
In Environmental Impact Assessment public participation is important. All those that may be influenced by possible nuisances from a new installation have the right to express their opinion on the proposal. The result of the EIA should be published in a report, and a public consultation should be undertaken, taking into account the comments and the report when making the final decision and informing the public about that decision afterwards. If a Court of Concession, or corresponding authority, decides on the permits, the public and in general all stakeholders have the right to have their say on the proposed new installation in the court process.

The Aarhus Convention insures that the public have access to information on the environmental effects of different projects. This convention was adopted by the Community in 2003 (Directive 2003/35/EC).

**What impacts are considered?**
The environmental impacts considered in an EIA assessment differ depending on national legislation, although some common ground has been created through the EU directive. Included are thus:

- Space intrusion, effecting a neighbourhood.
- Pollution, including pollution caused by transport.
- Effects on ecosystems and nature.
- Nuisance to society such as air pollution, noise, and odour.

More recently the social effects of a new installation have been stressed as important to consider. E.g. a new hydropower plant for which a large area is flooded to create a reservoir may cause villages to be set under water. Equally the opening of a new mine, especially strip-mining, may lead to replacement of whole populations. This may entail very difficult decisions where two important values, a social and an economic/environmental, have to be balanced.

A very central concern in EIA is the effect on biodiversity. This is especially underlined in developing countries and in the UN Convention on Biodiversity. If, e.g. a railroad is planned to go through areas with unique biotopes the company may be forced to choose a different way to get a permit.

Life cycle management, as described in the chapter, is also greatly concerned with economic consequences of the system. This is not part of the EIA or SEA, but it is always in practice an important concern in the final decision that may or may not lead to a permit to build and run a new system.

Sourcees:
International Association for Impact Assessment
*http://www.iaia.org/*

The EU Commission Internet site for EIA and SEA
*http://europa.eu.int/comm/environment/eia/*

L.R.

market and in disposal a complete overview of system information is necessary. This information should be provided by experienced systems engineers supported by the operators.

The same approach for determining the system functionality can be applied to determine the actual installation performance and physical condition. At this system level, experienced maintenance engineers supported by operators must provide the detailed content of this information.

Specific products and services could be relevant to achieving the most cost-effective manner of disposal for either the total system or the separate installations. Environmentally critical products or services must be flagged and assessed for their criticality using the Eco-Indicator method.

In line with these specific products and services the necessary *logistical activities* can be determined. In the disposal phase too it is important to determine the right logistical actors to perform the specified phase-out activities. In this phase specific attention must be paid to the quality specifications of the actors.

Based on the logistical actor specifications, the available resources are determined. This will give an idea of whether the available resources are adequate.

In the *Budget and Environmental Impact element* the cost and environmental impact estimate is based on the insight gained so far with accuracy depend on the available expertise and data available.

In Table 12.1d selected examples of types of products and services for LPC short list for Justify Phase-out phase are given.

## Study Questions

1. Describe the differences between functional- and technical functions by one or two examples.
2. How would you describe the installation performances for the technical function “provide electrical power”? Which type of data is needed.
3. Why is it important to get some insight in system effectiveness and installation performances versus operational need and budget, with respect to the environmental impact of the system?
4. How can the LPC be used to find means to minimize the environmental impacts?
5. How can the LPC be used for systems, which already exist?

## Abbreviations

| | |
|---|---|
| EIA | Environmental Impact Assessment. |
| IPPC | Integrated Pollution Prevention and Control. |
| LCM | Life Cycle Management. |
| LPC | Logistics Process Cycle. |
| SEA | Strategic Environmental Assessment. |

## Internet Resources

### Asset Management Control Research Foundation

http://www.amc-rf.com

### International Association for Impact Assessment

http://www.iaia.org/

### The EU Commission Internet site for EIA and SEA

http://europa.eu.int/comm/environment/eia/

# 13 Green Marketing and Eco-labelling

## 13.1 Communicating Environmental Performance

### 13.1.1 Communicating Environmental Performance

The introduction of Ecodesign and Life Cycle Assessment of products in companies of all kinds constitutes substantial efforts to map and improve the environmental properties of products and services. Obviously it is important that these efforts become known by all those concerned, not least by the customers and the market in general. Therefore it is crucial for companies to communicate their environmental performance and the environmental profile of their products to the customers. They want to reach a market of environmentally concerned customers in this way, and also create new customers groups by enhancing environmental consciousness.

At the same time there is a demand from large consumer groups to know more about the environmental profiles of the products they are offered in the shops.

These two needs are addressed by ecological labelling or eco-labels.

In the first situation it is the company that takes the initiative and may inform the market. In the second case consumer associations, green NGOs or other interest organisations may take the initiative and establish a programme for eco-labelling. A third important player are the authorities, mostly on state and multi-state union levels, which also use eco-labelling perhaps mostly as a way to implement environmental policies, and to promote and improve conformance to legislation.

Below we will scrutinise the different types of labelling that exist and see which role they play in green marketing. We will see if the two sides – the companies and the consumers – reach each other through this information. We will also see that there is a business-to-business information flow regarding the environmental properties of products and services, which is addressed by information tools, such as labelling.

However already here we should point out that labelling is not the only form of green marketing.

*Branding* means that a company makes itself know as an environmentally concerned and responsible business. This may be done in many ways, through advertising, environmental prizes, concern with resource use, through special information campaigns etc. Many examples of such companies are included in the short examples and cases given throughout this book. Well-known environmentally responsible companies include e.g. the Body Shop, IKEA, and some hotel chains.

**In this Chapter**

Another way is to get *certification for an EMS*, an environmental management system. Information that the company is certified may be included in information materials and administrative documents such as invoices, and also shown on signs on buildings, vehicles, products etc.

There is in addition a whole arsenal of means for communicating an environmental message. Brochures, logos, graphic design, exhibits etc. are there in addition to eco-labels, which thus should be seen as one tool out of many for green marketing.

### 13.1.2 Information Using Labels

Labels on products are used for many kinds of information, some required and some voluntary, some negative and some positive. Environmental information is also found in these categories.

The *legally required information* on *chemical products* includes the chemical content, especially if some of the ingredients are toxic, or otherwise dangerous, e.g. explosive or flammable, or ecologically hazardous. *Food products* often carry much more information on labels, such as comparative price, durability, caloric content etc. In addition information on if the food is organically grown, if animals are well taken care of etc is found on food packages. Equipment, such as *electrical equipment* has to be labelled with a series of technical information, including standardisation information. Much of the requested information is relevant for the environmental performance of the product.

The required information is often relevant for the environment. Nowadays many beverage containers – plastic, steel or aluminium bottles – have information if they are *recyclable*; in Sweden this is required by law as of January 2006, as non-recyclable bottles are outlawed. The label for recycling is today well known all over Europe.

Furniture may have information that it is *not made of tropical hardwood*. The timbering of such wood is threatening the residual tropical forests in the world and biodiversity, and thus environmentally negative. Increasingly often furniture may also have labels that it is made of wood from *certified forests* according to Forest Stewardship Council (FSC). These forests are timbered in a way that does not threaten biodiversity.

White goods, such as washing machines, refrigerators etc, or indeed all electrical equipment, may also have information on their *energy performance*, electricity use.

In addition to eco-labels products may also have so-called *social responsibility labels*. These labels ascertain that the products are produced with proper concern for labour rights, human rights, not using child labour etc.

Eco-labels are thus a rather recent addition to a long tradition of labelling; they have to fight for attention in the flood of information.

### 13.1.3 The Green Market

The market of green products is considerable. For example ecologically grown food has taken about 10% of the food market in e.g. Austria and Sweden, which represents several billion Euros. Swedish ecological food products are licensed by "KRAV", which is a company working under regulation of the State authority for agriculture. The producer of ecological food has to pay to the KRAV organisation to be audited, and receive a license and the right to label its products with KRAV.

The eco-labels are very attractive and some companies invent their own non-licensed labels, like a flower or forest etc, which however does not mean anything. On the United States web site for eco-labelling there are presently (2006) 137 different labels. Not all of these are under licensing by a third party.

Several environmental NGOs have their own green labels and organisation for licensing, such as the Swedish Falcon. These labels correspond to what the "green consumers" would like to see from a green product. However a series of other labels are created by industries and still others by the authorities. The EU flower for ecological products is created and licensed by the EU Commission. One may wonder if these correspond to customers requirements. In reality there are probably as many different requirements as there are customers. It is, however, perfectly possible to find out exactly what the labels mean by checking the web sites, and initially on the products themselves.

It seems that the voluntary eco-labelling is in the forefront and legal regulations valid for all products follow. There are many examples. Thus regulations on the use of biocides, nutrient recycling and animal welfare – originally promoted by enthusiasts – will make all food in EU have a rather ecological character in the near future. The stricter rules for chemicals, the top of the agenda of the environmental movement, is now being introduced with the REACH Directive, and will improve the environmental profile of all chemicals.

## 13.2 Eco-labelling

### 13.2.1 Three Types of Eco-labels

*Eco-labelling* is a voluntary method of environmental performance certification, a label which is used around the world. An *eco-label* is a label which identifies the overall environmental performance of a product or service within a specific product/service category based on life cycle considerations. In contrast to "green" symbols or claim statements developed by manufacturers and service providers, an eco-label is awarded by an impartial third-party in relation to certain products or services, which are independently determined as environmental leadership criteria.

The International Organization for Standardization (ISO) has identified three broad types of voluntary labels, with eco-labelling fitting under Type I.

- *Type I:* A voluntary, multiple-criteria based, third party program that awards a license that authorises the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations.
- *Type II:* Informative environmental self-declaration claims.
- *Type III:* Voluntary programs that provide quantified environmental data of a product, under categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party.

> The ISO 14020 standard defines eco-labels as labels which share a common goal:
> *"...through communication of verifiable and accurate information that is not misleading on environmental aspects of products and services, to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market-driven continuous environmental improvement."*

### 13.2.2 Why Eco-labels

The roots of eco-labelling are found in a growing global concern for environmental protection on the part of governments, businesses and the public. As businesses have come to recognise that environmental concerns may be translated into a market advantage for certain product: services, various environmental declarations/claims/labels have emerged on products and they have respect to services in the marketplace (e.g. natural, recyclable, eco-friendly, low energy, recycled content, etc.). While these have attracted consumers looking for ways to reduce adverse environmental impacts through their purchasing choices, they have also led to some confusion and scepticism on the part of consumers.

Without guiding standards and investigation by an independent third party, consumers cannot be certain that the companies' assertions guarantee that each labelled product or service is environmentally preferable alternative. This concern with credibility and impartiality has prompted the formation of both private and public organizations providing third-party labelling.

There are a series of sources for information on eco-labelling. Some of the more useful are:

*ISO standards.* Look at the International Organisation for Standardisation (ISO) and its standard 14020-23 for eco-labelling.

*The Global Eco-labelling Network (GEN).* They Publish an eco-labelling guide with much advice, and a discussion pa-

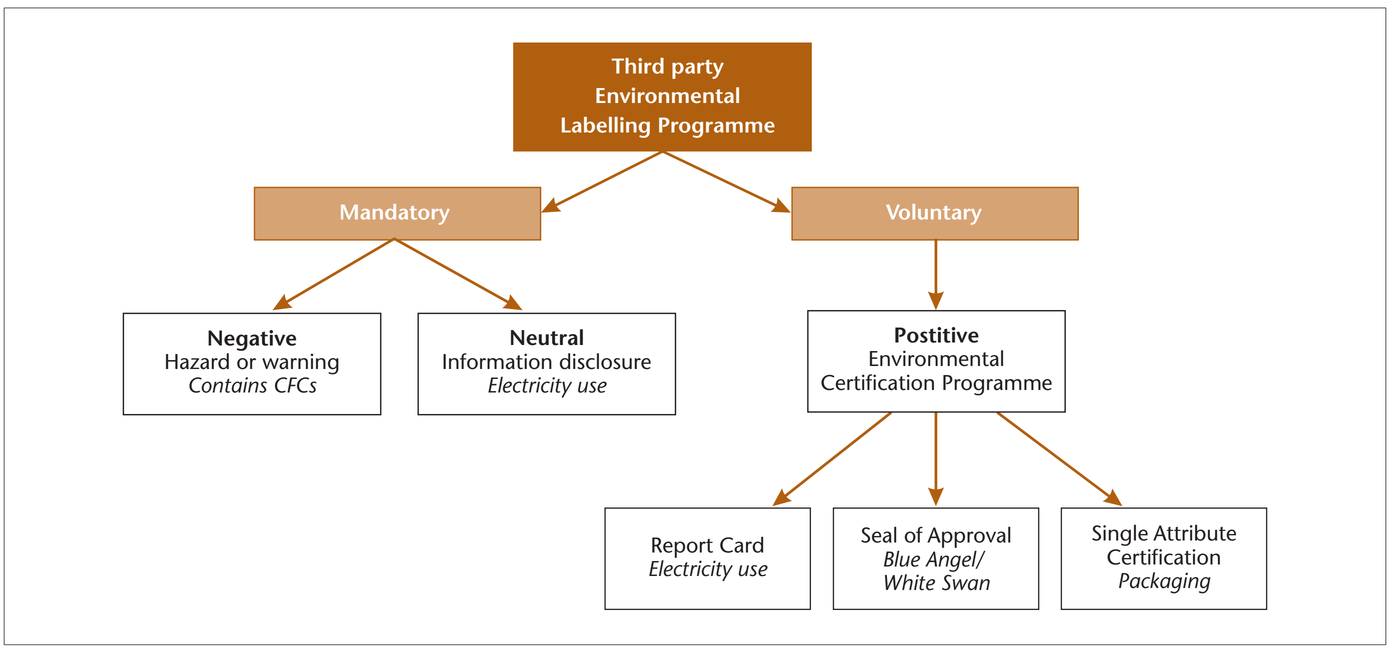



**Figure 13.1** *Different types of labelling programmes.*

per On Enhanced Co-operation [1999] (see Internet Resources). The GEN homepage is especially useful on the Type III eco-labels, with information and elaboration on eco-labelling strategies, issues and practices.

*The specific labelling programmes.* E.g. the Nordic Swan. See further below, and the list of Internet Resources.

### 13.2.3 Eco-labelling Programmes

An ecodesign product can also be offered for an independent environmental seal of approval, which will raise the level of consumer recognition. The US EPA published a summary of all the eco-labels that existed worldwide in 1993 (Table 13.1). Labelling programs can be positive, neutral or negative; that is, they can promote positive attributes of products, they can require disclosure of information that is inherently neither good nor bad, or they can require (negative) warnings about the hazards of products. Figure 13.1 gives an overview of the different types of labelling programmes.

Seal of approval programmes identify products or services as being less harmful to the environment than similar products or services with the same function. Single attribute certification programmes typically indicate that an independent third party has validated a particular environmental claim made by the manufacturer. Report cards offer consumers neutral information about a product and/or a company's environmental performance in multiple impact categories. These three types of programme, by virtue of their voluntary nature, have been grouped together as environmental certification programmes.

*Information disclosure* labels, like report cards, are neutral, disclosing facts about a product that would not otherwise be disclosed by the manufacturer. Unlike report cards, information disclosure labels are required by law.

*Hazard/warning labels*, or negative labels, are mandatory warnings concerning the product's adverse environmental or health impacts.

Of all these labelling programmes, the voluntary seal of approval programmes are the most comprehensive. They award a logo for products judged to be less environmentally harmful than comparable products, based on a specified set of award criteria per product category. How these product seal of approval programmes and evaluation award criteria are set defines the most important differences among the seal of approval programmes currently in existence. Table 13.1 summarises a number of seals of approval programmes and Figure 13.2 several different types of eco-labels.

Whether a company should apply for such a voluntary eco-label for its ecodesign products depends on many factors.

– The environmental requirements have to be established for the product category.

– Making an application may be expensive, especially if different labels (in terms of content) must be applied for in different countries for the same product.

**Table 13.1 Overview of Environmental Labelling Programmes**
*The table lists the date of origin of some of the best known labelling programmes [US Environmental Protection Agency, 1993].*

| Programme name | Country | Date founded |
|---|---|---|
| Blue Angel | Germany | 1978 |
| Environmental Choice | Canada | 1988 |
| Program Ecomark | Japan | 1989 |
| White Swan | Nordic Council (Sweden, Denmark, Norway, Iceland, Finland) | 1989 |
| Green Seal | United States | 1989 |
| Good Environmental Choice | Sweden | 1990 |
| Environmental Choice New Zealand | New Zealand | 1990 |
| Ecomark | India | 1991 |
| Ecomark | Korea | 1992 |
| Green Label Singapore | Singapore | 1992 |
| Environmental Labelling | European Community | 1992 |
| Programme Stichting Milieukeur | Netherlands | 1992 |
| NF-Environment | France | 1992 |
| Flipper Seal of Approval | International | 1992 |
| SCS Forest Conservation Program | United States | 1993 |

Many companies in Europe are waiting to see what happens with regard to the further development of the European label as a replacement for the specific labels used in individual European countries.

The decision to apply for an eco-label will depend a great deal on what the competition does and how significant a certain local market is for a company. Another important aspect is whether the requirements for the appropriate eco-label were taken into account when the objectives for the ecodesign project was formulated. It would obviously be nonsensical to apply for a label if the chances of being awarded that label were not good. In some cases the requirements for existing eco-labels do not go far enough for some companies. In such a case consideration could be given to setting up (possibly in conjunction with other businesses operating in the same branch of industry) one's own seal of approval with even more stringent requirements (as was done in the textile industry by Novotex, for example).

### 13.2.4 Environmental Product Declaration, EPD

Environmental Product Declarations (EPDs) are LCA results adapted for communication to the market. EPDs are thus strictly standardised and simplified; weighting is not used. EPD can be used for all products, and there are not any predetermined levels for the product per se. It is just a declaration of the LCA. Therefore an EPD in itself is not a guarantee that the product is environmentally friendly.

The environmental product declaration is a rather new instrument. The first programme, the Swedish one, was launched in 1998. The EPDs do not have such a wide global use as the eco-labels. Based on the Swedish experience the ISO organisation has introduced a procedure how to develop an EPD and developed the ISO/TR 14025 2000 standard. As the EPDs are highly standardised, they must comply with the standard.

EPD does not compete with eco-labels but has a slightly different focus. It is mostly used for business-to-business information.

The variations of the rules for different products are available in documents called Product Specific Requirements (PSR). In the PSR for a product category, the functional unit is described, and the exact information which should be available in the product declaration. The PSR are developed by the market, that is, the companies. The EPD declaration gives specific information for each life cycle phase of the products (raw material, use phase, waste phase) including recycling. Verification of EPDs is done by the same authority as for the verification of the EMS ISO 14001 or EMAS.

## 13.3 Green Marketing

### 13.3.1 How Green Marketing Influences a Company's Image

If a company has a poor environmental image it cannot be changed overnight by launching a single environmentally-sound product if the company's other products remain as they are. In order to (re)position the company with the help of the new, ecodesigned product one should ask: what are the main themes the company wishes to be identified with and what are the subjects it wishes to discuss? Key issues for positioning a company as a business that wants to help create a healthy environment are:

- A tradition of pursuing a sound environmental policy.
- Openness towards consumers and those living in the vicinity of the plant.
- An image of high-quality and reliable products.
- Being a leader in the field, for instance by being the first company to have an in-house environmental management system certified by EMAS, British Standards or ISO, or a Corporate Environmental Report of the ecodesign programme.
- Extensive research into the environmental aspects of products and processes, to be recorded in product dossiers.
- Excellent contact with consumer and environmental organizations with a view to anticipated, future environmental requirements.
- Involvement in environmental research programmes with universities and institutes of applied research and international environmental programmes, such as those of UNEP, EUREKA, etc.
- The image of being a responsible company willing, for example, to take back both product and packaging, to reuse components and to recycle materials.

To position a company sensibly it is wise not to exaggerate or boast about achievements but rather give a true picture of the situation, to be honest about the problematic aspects of products and processes, even in the public debate, and finally to recognise environmental problems that are relevant for customers and explain how ecodesign can reduce or even prevent them. Doing this will increase the consumers' knowledge about environmental matters and, in due course, raise their level of involvement.

Marketing based on environmental arguments is appropriate for service products which were set up with environmental arguments in mind (call-a-car, collective laundry service, toner cartridge recycling services, photocopier leasing, etc.).

## Eco-labels

The following examples of eco-label schemes include programmes initiated and run by state authorities, green NGOs and producers associations. The texts are abbreviated and edited from the homepages referred to.

### 1. European Commission EU Flower

The EU flower is available to a range of products and services. The scheme, which has been designed and is overseen by the European Commission, sets out specific ecological criteria that products must comply with to be certified as environmentally friendly. The award of the label is independently verified and endorsed by the European Commission. The EU Flower is a recognised environmental quality mark across the countries of the EU and in Norway and Liechtenstein. A key step in assessing a product for the EU flower is the completion of an environmental life-cycle assessment. The EU is currently introducing IPP that will use instruments such as greener standards and environmental taxes to force producers to take account of the environmental impact of their products throughout their life-cycle. Products with the EU Flower will have been assessed for such impacts and will usually comply with these schemes.

The EU Flower has been shown to help sales in other EU markets. Cleaner production required to reach Eco-label criteria can be cheaper and more efficient. It also prevents potential costs associated with waste and pollution. There is a demand for environmentally friendly products among consumers and retailers. The EU Flower could help producers to become a preferred supplier – particularly in the governmental sector.

*http://www.eic.ie/faq_euflower.htm*

### 2. Nordic Council of Ministers The Swan

The Swan is the official Nordic eco-label, introduced by the Nordic Council of Ministers. The green symbol is available for around 60 product groups. Everything from washing-up liquid to furniture and hotels can carry the Swan label. The Swan checks that products fulfil certain criteria using methods such as samples from independent laboratories, certificates and control visits. The label is usually valid for three years, after which the criteria are revised and the company must reapply for a licence. The Swan label is well-known. 67% of people in the Nordic countries understand the Swan.

Products are evaluated in relation to the specific environmental problems throughout its life cycle, the possible environmental gain and how the product, activity or problem might be affected by the eco-label. The criteria are finalised by the Nordic Eco-labelling Association. A company has to pay an application fee and an annual fee to receive the licence, to cover costs for administration, audits etc. Application fees varies from 3,500 DKK in Denmark to 2,000 Euros in Finland, 12,000 NOK in Norway and 18,000 SEK in Sweden. The annual charge is 0.3 or 0.4% of turnover. There is a maximum fee.

*http://www.svanen.nu/Eng/about/*

### 3. Swedish Society for Nature Conservation Good Green Buy

The Green Consumerism project of SSNC covers several approaches to green consumerism and eco-labelling. The active members, who devote their interest to local activities of the nation-wide campaigns such as the Annual Greening Campaign etc., together form the green consumerism network. *Bra Miljöval* is the eco-label of SSNC. It is referred to as "Good Green Buy" or "Good Environmental Choice" in English. SSNC started eco-labelling in 1988 on laundry detergent and paper. Currently the system covers 13 product areas. The eco-labelling also includes the internationally introduced labelling system of TCO '95 and '99 on computers.

Procurement at all the various offices all over Sweden is the focus of SSNC's *Green Office project*. Decisions on whom to contract and what to buy are important as a driving force towards sustainability. The Greening Office Project helps to put up relevant environmental criteria for procurement purposes. SSNC's *eco-labelling of electricity delivery contracts* started in 1996. Both supply and demand of the labelled services are expanding rapidly. Since May 1998, the same criteria are working in Norway and Finland in cooperation with SSNC's sister organizations.

*http://www.snf.se/bmv/english.cfm*

### 4. The Polish Eco-label. Polish Centre for Testing and Certification (PCBC)

Polish Centre for Testing and Certification (PCBC) is Poland's leading organization acting within the EU conformity assessment system. PCBC is a state-owned company with responsibility for testing and certificates for the EU, according to regulations for products; test and certification of products for the voluntary conformity labels B, Q, EKO; certification for CB and CCA, and the certification of management systems for quality, environment, occupational health and safety management systems, etc. as well as the training of quality personnel. PCBC is the EU Notified Body for a number of EU Directives such as safety of toys, electromagnetic compatibility, low-voltage electrical equipment etc.

*http://www.pcbc.gov.pl/ang/index1.htm*

### 5. Organic Food Market in Sweden, KRAV

KRAV, a key player in the organic market in Sweden, inspects and promotes the *KRAV* label. It is organised as an incorporated association with, at present, 28 members. They represent farmers, processors, trade and also consumer, environmental and animal welfare interests. KRAV has about 70 employees, nearly half of whom are full-time inspectors.

Organic production exists all around the world. KRAV is an active member of the International Federation of Organic Agriculture Movements (IFOAM), an umbrella organisation which gathers organisations for farmers, scientists, educationalists and certifiers from almost every country in the world. KRAV takes an active part in developing the IFOAM standards and also works to influence the EU organic production legislation.

KRAV's standards meet the IFOAM Basic Standards and the EEC regulation for organic production, and KRAV is accredited by IFOAM and authorised by the Swedish National Board of Agriculture and the Swedish National Food Administration to carry out inspection of organic production in Sweden. In Sweden the area for organic agriculture in 2005 was 200,010 hektar. Production increased in 2004 to 1.9 billion SEK at the wholesale level.

*http://www.krav.se/english.asp*

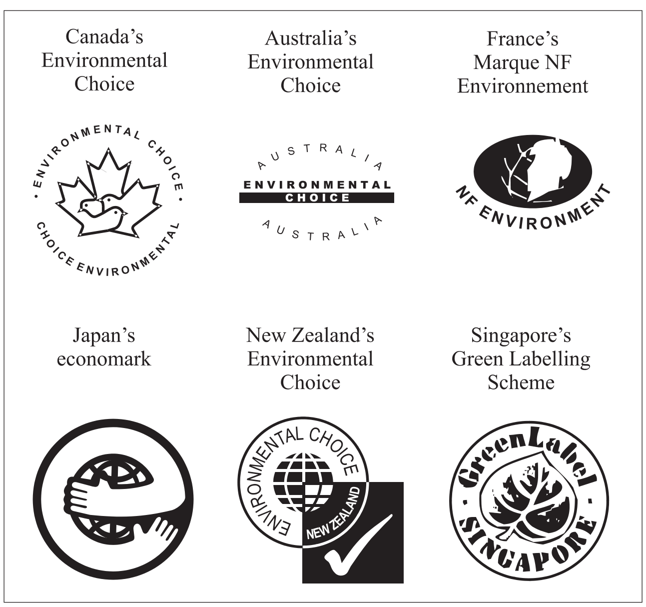



**Figure 13.2** *Other environmental labels worldwide.*

### 6. Latvijas Ekoprodukts

Latvijas Ekoprodukts organize 550 ecological farmers in Latvia. The eco-label is a green four-leaf clover in a horseshoe with the text Latvijas Ekoprodukts. There are only two bakeries in Latvia that bake bread using ecological flour, and that have permission to use the eco-label on their produkts. The bread, apples, carrots and honey have been grown without artificial fertilisers and biocides. A major difficulty for Latvijas Ekoprodukts faces is that organically grown food is slightly more expensive than conventionally produced food.

#### Swan Product Categories 2005

There are 680 licenses and 60 product categories (listed below) for the Swan in Sweden today.

Batteries Rechargeable; Building materials: chipboard, fibre board and gypsum board; Car and boat care products; Car Wash installations; Cleaning products; Cleaning services; Closed fireplaces for biofuel; Closed toilet systems; Coffee filters; Composts; Compressors; Copying machines, printers, fax machines and multi-functional devices; Cosmetic products; De-icers; Dishwasher detergents for professional use; Durable wood – Alternative to conventionally impregnated wood; Film forming floor care products; Flooring; Furniture and fitments; Grease-proof paper; Hand towel roll services; Hand washing up liquid; Hotels; Industrial cleaning and degreasing agents; Kitchen appliances and equipment; Laundries; Laundry detergents and stain removers; Lawn-mowers Light sources; Lubricating oils; Marine engines; Microfibre cloths and mops; Oil burner/boiler combinations; Outdoor furniture; Packaging paper; Paper envelopes; Pellets; Personal computers; Photo Finishing Services; Printed matter; Printed Wiring Boards; Printing paper; Refrigerators and Freezers; Sanitary Products; Shampoo, conditioner, body shampoo, liquid and solid soap; Small heat pumps; Small Houses; Solid Biofuel Boilers; Supermarkets Grocery stores; Textiles; Tissue paper; Toner cartridges; Washing machines; Vehicle tyres; Windows; Working machines, park and garden; Writing instruments.

Examples of companies which use "green marketing" with success are ESPRIT, Norsk Hydro, BSO/Origin, Ecover and The Body Shop. These are sources of inspiration as they illustrate that environment and trade can indeed go hand in hand.

### 13.3.2 What are the Risks Involved in Green Marketing?

A few simple rules should be recognised in environmental marketing. Unjust environmental claims, which at a later date have to be withdrawn because of the negative publicity it has aroused, can do irreparable damage. This applies not only to the product in question but to the credibility of the company as a whole. One common mistake in "green marketing" is attempting to present a product as being ecologically sound on matters of little importance; for example, the manufacturer of an electric lawn mower who advertises that the instruction manual is now printed on recycled paper.

Some governments have established special regulations designed to monitor green marketing claims. These regulations include the Australian Trade Practice Commission's *Environmental Claims in Marketing – A Guideline* and the US Federal Trade Commission's *Guide for the Use of Environmental Marketing Claims*. These regulations are all designed to ensure that consumers have the appropriate information with which to evaluate companies' environmental claims. In the United States, in addition to these guidelines, many states have introduced legislation to control environmental marketing activities. Appropriate green marketing claims should:

- Clearly state environmental benefits, based upon a verifiable Life Cycle Assessment procedure.
- Explain environmental characteristics.
- Explain how benefits are achieved.
- Ensure that comparative differences are justified.
- Ensure that negative factors are taken into consideration.
- Use only meaningful terms and pictures.

Nevertheless, the debate about the most environmentally sound measures is an ongoing scientific debate. Businesses will have to learn to live with the fact that what they consider – underpinned by certain LCA analyses – "green" can be seen differently by governments, environmental pressure groups and consumers. They will also have to take into account the fact that products now regarded as ecologically sound may be judged less so in the future on the basis of new scientific findings.

### 13.3.3 Translating Environmental Merits into User Benefits

Environmental merits of a new product also need to be relevant for the customers, if they are to see it as a reason to buy the product. It is obviously important to indicate that the environmental merit can also have a personal advantage for the user. Table 13.2 gives several examples of environmental merit which can also be seen as advantageous to the user.

However, for certain consumers the environmental aspect could be perceived as a disadvantage rather than a potential advantage. In this case, good environmental performance is not a reason to buy a product, although still bad environmental performance may be a reason for not buying the product.

Intermediaries have an important role in green marketing, and a company has to be able to communicate the environmental merits and other qualities of new products to intermediaries which form the link to the market: retailers, wholesalers, fitters, electricians, service organizations, etc. It is consequently important to involve several such people when setting up the information plan. In the case of technical products, special training courses and service support will be necessary to make proper installation and after-sales service possible. The product's launch should be timed to avoid unnecessary resistance on the part of the distributive trades.

In some cases, intermediary innovation organizations with government connections are prepared to fund much of the

**Table 13.2** *Environmental merits with benefits for the user.*

| Environmental merit | Advantage for the user |
|---|---|
| Integrated functions | One device; a modular-designed fax and modem combination instead of a separate fax and modem |
| Raising the level of sustainability | Longer life and lower maintenance cost (e.g. furniture or floor covering) |
| Closing cycles | Guaranteed product or appliance take-back upon disposal (e.g. television, washing machine) |
| Energy conservation | Lower energy costs when using the product (e.g. central heating boiler, hot plate) |
| Different or less material | Lighter, easier to handle product (e.g. racing bike) |
| More efficient logistics | Less packaging waste (handling, cost) for the consumer |
| Other advantages could be | Safer product; easier to clean; simple to install or assemble; easy to maintain or to repair |

marketing costs if, for instance, the product is an environmental innovation which is significant to us all (such as a solar-powered boiler or an energy-saving bulb). For the marketing of product take-back systems (cars, packaging, electronics), the industry itself will generally set up its own special organization for promoting the take-back system. Also other stakeholders, such as environmental pressure groups and consumer rights movements, have acted as important intermediary organizations between companies and consumers. For instance McDonalds used these organizations successfully in their green marketing approach.

### 13.3.4 Green Products

The EU Commission in its Green Paper on eco-labels suggested that an examination of the existing types of environmental labelling is made, to consider whether a strategy on wider labelling should be drawn up by the Commission. If consumers demand green products, markets are likely to provide them. However, consumers need information to choose between different products. There is considerable potential for public procurement, which represents around 12% of Community GDP to stimulate green demand. The Green Paper recognises the need to examine Community public procurement law and its possibilities for giving preference to environmentally friendly products. Another possible tool suggested is some form of exchange of experience between procurement authorities.

Getting the prices right is probably the single most effective measure available to stimulate markets for greener products. The consumer is most likely to act if they can feel the advantage in their pocket. Ideas suggested for discussion include:

- Differentiated taxation such as reduced VAT rates on eco-labelled products.

- An extension of the producer responsibility concept to new areas.

- The use of state aid-policy within the New Guidelines on State Aid for Environmental Protection.

### Box 13.1 A Checklist for Green Marketing

Launching a new product needs special attention. There are certain aspects which differ from the usual techniques used for introducing a product onto the market. Here is a checklist.

1. Can the environmental merits that have been achieved be communicated convincingly to the market?
2. Is there any link between the environmental merit and the product's main function? The closer the environmental merit lies to the product's main function, the more important it is to promote the environmental results of the new design.
3. The more technical a product, and the more crucial the role of its distribution, the more account should be taken of the wishes of the distributive trades when designing publicity material, setting up sales support and training facilities, and when timing the product's launch.
4. Occasionally, a product's environmental aspects can become the subject of public debate. This provides opportunities for positioning the product when it is launched. Nevertheless, there is also an element of risk if it later becomes apparent that the environmental claims cannot be substantiated.
5. If the environmental improvements constitute a real breakthrough there is always the chance of free publicity in the media, the chance that you might be granted an environmental seal of approval, or that you might be given an environmental award.
6. If the product must meet certain norms and standards, or has to be subjected to tests (ISO, etc.), it is important to have the product inspected by an independent body and to have the results published.
7. Keep a close watch on agreements made by international organizations and multinational as to standards and product-specific environmental information, and take this into account in the management of your own business.
8. Consider submitting the product for prizes and awards for industrial environmental design.
9. Prior to the launch you must decide whether, and if so how, patenting and/or model protection should be sought. Contact universities and research institutes for support in researching the degree of innovation of the product.
10. Make sure that any agreements made internally or with specialist firms for taking back the products, and for their reuse or recycling, are set down in writing before the product or product information is launched.
11. Make a cost-benefit analysis in connection with a (potential) application for a voluntary eco-label or a special recycling logo. If followed up, work on the basis of legal regulations.
12. Analyse the activities of other companies known to be trend-setters in the field of green marketing which are of interest to your company.

Once a product is put on the market, it is difficult to reduce its impacts. By focusing on their environmentally friendly design environmental impacts could be prevented. Possible ways to improve ecodesign include:

- Improving the generation and flow of life-cycle information.
- Encouraging ecodesign guidelines.
- Integrating environmental considerations into the standardization process.
- Reviewing the approach of so-called "New Approach" legislation, such as the Packaging Directive and the planned Directive on Electrical and Electronic Equipment.

A new method for considering the life-cycle aspects suggested by the Green Paper is "Product Panels". These are groups of relevant stakeholders who seek to devise solutions to particular problems.

## Study Questions

1. Describe the difference between eco-labelling and branding.
2. Describe the purposes behind the introduction of eco-labels.
3. Describe how the image of a company can be influenced by the use of eco-label(s).
4. What are the reasons for customers to buy eco-labelled products?
5. What kind products, not mentioned in this chapter, may be given an eco-label?

## Abbreviations

| | |
|---|---|
| EPD | Environmental Product declarations. |
| EMAS | Eco Management and Audit Scheme. |
| EPA | Environmental Protection Agency. |
| FSC | Forest Stewardship Council. |
| GEN | Global Eco-labelling Network. |
| ISO | International Standardization Organization. |
| PCBC | Polish Centre for Testing and Certification. |
| PSR | Product Specific Requirements. |

## Internet Resources

The Global Eco-labelling Network (GEN)
http://www.gen.gr.jp/publications.html

The European Union Eco-label Homepage
http://ec.europa.eu/environment/ecolabel/index_en.htm

The Eco-label The Swan
http://www.svanen.nu/Eng/about/

Swedish Society for Nature Conservation.
Green consumerism and Eco-labelling
http://www.snf.se/bmv/english.cfm

Polish Centre for Testing and Certification (PCBC)
http://www.pcbc.gov.pl/ang/index1.htm

KRAV – Organically Grown Food in Sweden
http://www.krav.se/english.asp

Ecodesign Centre
http://www.alternatis.be/

Consumers Union Guide to Environmental Labels, USA
http://www.eco-labels.org/home.cfm

International Organisation for Standardisation
(ISO 14020 and 14024)
http://www.iso.org

BSD Business and Sustainable Development – A Global Guide
http://www.bsdglobal.com/markets/eco_label_iso14020.asp

International Institute for Sustainable (Canada)
Development on Eco-labelling
http://www.iisd.org/trade/handbook/5_4_2.htm

GreenBiz
http://www.greenbiz.com/toolbox/

WTO (World Trade Organization)
Submissions on Trade and Environment
http://www.trade-environment.org/page/theme/tewto/para32iii-item3.htm

Directive 2005/32/EC on the Ecodesign of
Energy-using Products (EuP)
http://ec.europa.eu/enterprise/eco_design/index.htm

# 14 Management Tools for Product Life Cycles

## 14.1 The Management Systems Landscape

### 14.1.1 Management Systems

The last few decades have focused on a number of different approaches to management. There is quality management, environmental management, and risk management, just to mention a few. They all have the same purpose: to guide the company or organisation in a complex reality. They all have in common that they need to be properly integrated into the day-to-day operations to be successful.

The overall management system aims to support developing, implementing, achieving, reviewing and maintaining the *policy* of an organisation or company. They refer to the organisational structures, planning activities, responsibilities, practices, procedures, processes and resources in the organisation or company.

The person using a management system is *manager*. A manager is a problem-solver, and the fundamental activity in problem-solving is *decision-making*. Decision-making is the process of identifying a problem, identifying alternative solutions, and choosing and implementing one of them.

The manager establishes a *strategy*. A strategy can be described as "a pattern in a stream of decisions". This indicates that strategic work is a continual process. Strategic decisions can be recognised by complex, unstructured and non-standardised factors of vital importance to the organisation.

This stresses the special need for solid bases for strategic decisions and an information system designed to handle it.

### 14.1.2. Environmental Management Systems (EMS)

Below we will focus mainly on *Environmental Management Systems (EMS)*. EMS addresses the environmental policy of the company. EMS is a specific management system related to the other management systems. It is covered by standards such as ISO, DIN EN ISO 14001:2004, and 1996-10.

In fact an EMS will be applicable for every system or subsystem as long as the system boundaries are well defined, for example, the world climate system, the international transport system, the agriculture system, the production system of consumer goods, the health care system – or your own daily system.

Here we will mostly discuss one type of system: the design, production, use and disposal of a product. This is called the *primary system* or *production system*. An EMS will always be relevant for any subsystem of the primary (production) system observed.

It is important to stress that a modern system of environmental protection should be based on a solid legal, organi-

**In this Chapter**

1. The Management Systems Landscape.
    - Management Systems.
    - Environmental Management Systems (EMS).
    - Life Cycle Assessment/Analysis (LCA).
    - Policies and Goals.
    - Methods and Techniques Mapping (M&T).
    - A General EMS Model.
2. Life Cycle Management (LCM).
    - Life Cycle Analysis of Systems.
    - Life Cycle Inventory (LCI).
    - Information and Data Management.
    - LCA Process Management.
    - Team Management.
3. Survey of Management Tools.
    - An Overview of LCA Related Management Tools.

sational, economic and technological foundation. To treat environmental protection in a comprehensive way the most important elements of the environment, and environmental pressures should be integrated with the economic dimension. This is the concept of *eco-development*.

### 14.1.3 Life Cycle Assessment (LCA)

*Life Cycle Assessment* (sometimes called *Life Cycle Analysis)* is of increasing importance for management of a production system. *Life cycle* refers, as already described, to the entire life of a product, from extraction and processing of the raw material, transport of the resources to the production facility or factory, the manufacturing of the product, the use and maintenance of the product, and finally its wasting or possible reuse or recycling. LCA is also called from cradle-to-grave, or sometimes and even better, from cradle-to-cradle, since, in the end, nothing is lost. It just appears in a different form to serve some purpose. The *analysis* of the life cycle of a product takes into account all these stages to, most often, get an overview of the totality of the environmental impact of a product. Since this analysis is seldom exact, the word *assessment*, which indicates an estimation or an approximation, is often more appropriate.

A correct understanding of the entire life cycle of a product aims to provide a basis for decisions which will promote sustainable development of our economies. Its strength is first of all related to the development of cleaner production and products, in order to reduce material and energy use and emissions harmful to the environment [Cowell et al., 1997]. The LCA method is being adopted by the International Organisation for Standardisation and documented in several standards (ISO DIS 14040-14043).

Although LCA is still a young scientific field, it has developed rapidly towards consensus on a large number of key issues. The adoption of LCA has grown along with these developments. On the other hand, the high level of expert knowledge, high data demands and high costs may impede widespread use of LCA, especially for environmental issues. Furthermore, many methodological choices are required and a number of aspects need to be further worked out, potentially jeopardizing the credibility of the outcome of LCA studies. This may lead to decreasing confidence in, and use, of LCA by industry and governmental institutions [Cowell et al., 1997].

### 14.1.4 Policies and Goals

Policies are general directions for an organisation or company. For example it may be the policy of an organisation, such as a university, to treat men and women equally or it may be the policy to be environmentally friendly. When policies are implemented they need to be made more concrete, and they should be formulated into goals. Companies and other organisations have – or should have – clearly formulated goals. Examples of goals are e.g. that 50 % of the students of a university should be women, that a certain quality, or a defined level of environmental performance, or a defined level of economic turnover or profit etc. should be reached in a company. Goals, to be useful, should fulfil the requirements to be:

- **S**pecific.
- **M**easurable.
- **A**ttractive.
- **R**eachable.
- **T**ime limited.

This is the SMART rule. If goals are SMART, it will be easier to communicate them within the company or organisation and also to the outside, e.g. to customers. It will also be easier to follow them and know where you are in the efforts to reach the goals. And, very importantly, it will be easier to use a management system to implement them.

### 14.1.5 Methods and Techniques Mapping (M&T)

With the *Methods and Techniques (M&T)* mapping method [Stavenuiter, 2002] it is possible to describe a management system or tool in a 2-dimensional space (X,Y) defined as follows:

- The X-axis represents the process life cycles of the primary system concerned.
- The Y-axis represents the specific management activities.

The X-axis, the life cycle of a product, is here divided into six stages: Three design stages, (concept, preliminary and detailed plan), a production stage (Realization/implementation), a use stage (Utilization/maintenance) and a waste stage (Phase out):

- Conceptual idea.
- Preliminary plan.
- Detailed plan.
- Realization/implementation.
- Utilization/maintenance.
- Phase out.

The Y-axis, management activities, is divided into seven stages:

- Goal setting.
- Policy determination.
- Planning.
- Organising.
- Directing.
- Controlling.
- Accounting.

The M&T mapping method is developed to place methods and techniques in relation to these two dimensions, the life cycle stages and the management stages. They can be arranged on the map for easy reference. You can see where in the process a specific method or technique is relevant. When more than one method or technique is entered on the map, you get an easy overview of how the service areas overlap and give insights into their interrelationship. An M&T map is illustrated in Figure 14.1.

To avoid any misunderstanding the terms method and technique are defined as below:

A *Method* is a specific, well-developed and described *procedure* to support specific business activities or processes [De Leeuw, 1997].

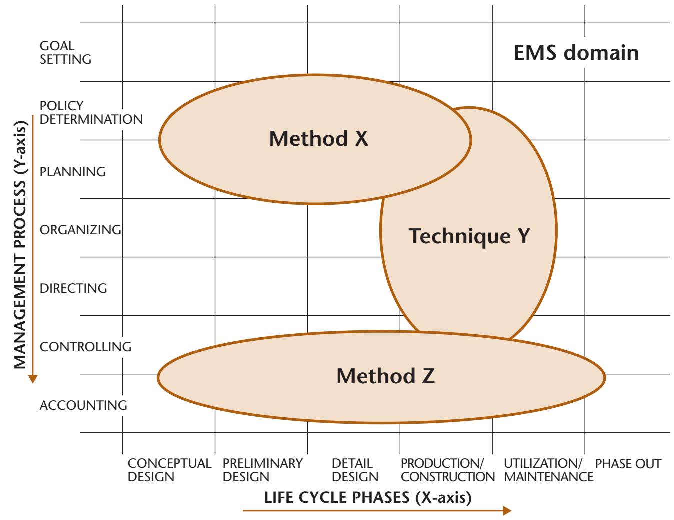



**Figure 14.1** *Example of overlapping service areas.*

## Box 14.1 Environmental Action Program of Poland

**Strategic directions:**

- The shaping of macro-economics (fiscal, commercial, monetary and credit).
- The adjustment of sectoral policies to the sustainable management of natural resources and a reduction in the pressure imposed on the environment.
- The shaping of sustainable models of consumption and a reduction in the level of materialism inherent in lifestyles.
- An improvement in the quality of all components of the environment in all specific areas.
- The ensuring of public access to information on the environment.
- The promotion of sustainable development.

**Tactical directions:**

- The improvement and development of legal, administrative, economic and financial regulations and institutions concerned with the utilisation of environmental resources.
- The improvement of structures involved with environmental management at all levels of the central and local government administrations.
- The promotion of the principles of and systems underpinning environmental management at the level of the factory, enterprise or institution.
- The effective negotiation with international bodies, such as the EU, to meet the international adopted requirements in area of the environmental sphere.
- The application of environmental reviews.

**Operational directions of action, sector-wise (selected sectors):**

*Power supply and industry:*

- The promotion of Environmental Management Systems.
- The introduction of methods and technologies for cleaner production.
- Improvements in energetic and raw-materials efficiency.
- The use of alternative materials and renewable energy sources.

*Agriculture:*

- The application of good agricultural practices.
- The setting-up of a certification system for food.
- Support for the production of organic produce and for organic farming.
- The reclamation of degraded land and the reforestation of wasteland.

*Tourism:*

- A reduction in the intensity of tourist traffic in areas of particularly valuable natural features.
- A change in a more environment-friendly direction to the models and forms of tourism.
- The promotion of environment-friendly forms of tourism.
- The improvement of tourist infrastructure and the quality of services offered.

*Health protection:*

- The introduction of a classification and system for the identification of diseases and syndromes that is set against an environmental background.
- The introduction of environmentally safe methods and technologies for the disposal of hazardous medical wastes.

A *Technique* is a well-known specified *way of working or treatment* to execute an activity or a process [Juran and Blanton, 1999].

In the M&T map the EMS domain is placed in the right half, meaning that it refers to the production, use and phase-out of a product (Figure 14.1).

The LCA domain is on the other hand used in the planning and design phases of a product. It is thus placed in the upper left-hand corner of the M&T map. The LCA method is seen to be useful during the development of the conceptual idea and the preliminary plan. It can support goal setting and policy determination.

### 14.1.6 A General EMS Model

To understand the means and feasibility of LCA, a systems approach is considered, based on the general system model of De Leeuw [1997]. A basic EMS model is dedicated to this topic. De Leeuw [1997] considered four interrelated system levels:

- The environment.
- The management system.
- The logistics system.
- The technical system.

Figure 14.2 illustrates how the four levels are defined for Environmental Management Systems. The logistics system and the technical system together constitute the production. The products are delivered to the environment, which provides resources and requests products. The management system is found in the centre.

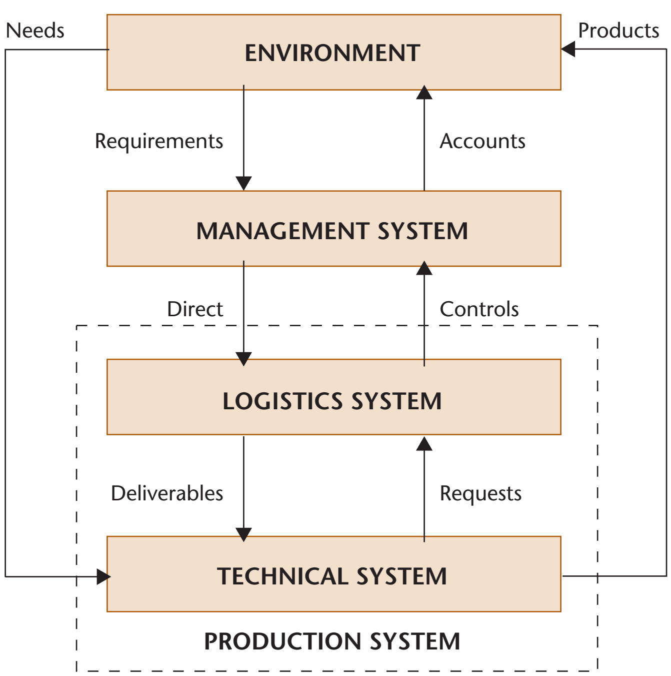



**Figure 14.2** *Basic EMS model.*

The logistics system in the production includes such actors as e.g. the design department, the workshop, the specialised contractor and so on. The functional parts of the technical system include the components of the manufacturing process, the factory, if you wish. These are the functional parts of the system. The components of the systems are of course different if the system considered is something other than manufacturing of a product, e.g. related to services.

## 14.2 Life Cycle Management (LCM)

### 14.2.1 Life Cycle Analysis of Systems

In a well-functioning process the technical and logistics systems meet the demands of the process during the entire life cycle of a product. This rarely happens, however. They need to be constantly monitored and corrected. This is the process of *Life Cycle Management (LCM)*. The job of an LCM is to control the technical and logistical system, and analyse them throughout the life cycle of the product.

For effective management, good control is needed. In general control systems should have the following properties to be working well [De Leeuw, 1997]:

- Realistic objectives.
- Relevant control measures.
- Knowledge about the effects of control measures on the system to be managed.
- Knowledge about the environmental influences of the system.
- Knowledge about the current state of the system.
- Sufficient data-processing capacity for the disposal of information relevant to taking the right control actions.

### 14.2.2 Life Cycle Inventory (LCI)

A *Life Cycle Inventory (LCI)* Analysis is structured in view of the production system. A Life Cycle Inventory consists of numerous individual elements. These are: economic elements, such as market information, i.e. contracts and physical elements, such as information on machinery and infrastructure.

Based on such a system model, LCA provides environmental information complementary to private cost statements.

In an LCI the emphasis is often put on inconsistencies encountered in the set-up of LCI system models, representation of decisions and value choices of actors (e.g., firms) involved in a production system, and the representation of changes within the economic system.

In an LCI analysis environmentally relevant in- and outflows of a defined production system must be gathered. The material and energy used in the production system must be allocated and determined by a functional unit or a functional flow.

The function of a technical system may for example be the production of a certain product and the functional unit may have been chosen, for example, 1 kg of that material. Examples of inflows considered relevant are natural resources, raw materials, energy, ancillary material etc. Examples of outflows are products and by-products, emissions to air, water and soil, waste etc.

Examples of models of production systems are individual process steps or production lines within a site, entire plants, transports and transportation routes, and complex composite systems such as production systems for specific products from cradle-to-grave.

A model of a technical system may have an inner structure, i.e. be composed of models of technical subsystems. For example, when performing an LCA, a flow model of the production system under study is accomplished by linking models of smaller technical systems together in a flow chart.

Examples of choices made in the modelling are the choice of production unit, what to include within the LCA system model and what can be included within the product LCA. In the product LCA the in- and outflows are considered environmentally relevant, which results for instance in a quantified Eco-Indicator Value.

### 14.2.3 Information and Data Management

Obviously the system and process structuring methods require extensive information and communication facilities. For this reason an LCA analysis should be provided with a flexible database system based on modern distributed database principles.

Questions to be answered regarding the information and communication structure are:

- *What* information will be required.
- *How* to collect, classify, document and communicate, this information.

Implementation is likely to vary depending on the situation. This means that for each implementation phase the particular specifications must be provided.

In general a data set displays types of objects and data and their internal relations. The basic idea for a LCA analysis data set is to achieve a data model that represents the real system in such a way that data is easily accessible for analysts, logisticians, operators, etc.

For the LCA data set, an inventory has been made of the entities and attributes discussed in the previous paragraphs, i.e. the system, functions, installations, products & services and actors. The data set kernel is built up of these entities. Figure 14.3 represents the kernel surrounded by the information records which are defined in line with the international standard (LSAR).

The *Product Data Management (PDM)* approach is selected to develop the information and communication architecture. Within the LCM-*systems* [Stavenuiter, 2002] a Web-based PDM approach is developed, indicated as PDM 2000 (see Chapter 8). It is based on (proven) Internet and database technologies and developed as a generally applicable approach.

The use of principles such as *Active Server Pages (ASP)* makes the user interface very flexible and provides the opportunity to use it also as *user information request form*. This kind of web page technology offers a free choice in Web page design and in ways of combining various data, stored in different databases.

### 14.2.4 LCA Process Management

The first step of the LCA process management approach is an analysis of the system objectives in relation to the logistic actors, the corporate aim and the work environment. The corporate aim, in this context, is to achieve (more) cost-effective and environmentally friendly utilisation of the technical system. In relation to this aim, the work environment is the complete production system as defined in a management, logistics and technical system.

LCA process management aims at creating an LCA-team as a self-steering team of professionals according to the *Learning Organisation (LO)* methodology. The aim of the approach is to provide basic applicable knowledge to create the pre-

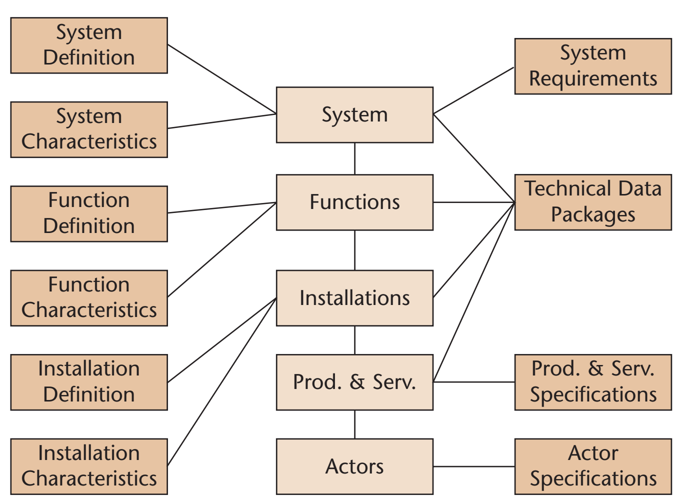



**Figure 14.3** *The conceptual LCM data set.*

conditions for transforming the LCA-team into a well-trained self-steering team with the following characteristics:

- Process-oriented.
- A flat hierarchical structure.
- Focused on corporate objectives.
- Learning from their own experiences and past history.
- Learning from the experiences and successful practices of others.
- Operational autonomy.

**Box 14.2 Development of the Organisation, and Training of the Individual**

According to Senge there is a dynamic reciprocal relation between the development of the organisation and the training of the individual actors. The extent to which training takes place, and its effectiveness, depends greatly on the training conditions offered by the organisation. A key factor is the influence of the actor´s training effort on the development of the organisation. When this is not visible the attempts to change things can count on resistance and opposition.

The incentive to learn and train should come from questions which appeal to the individual actor, such as: can we do it better, smarter, faster, easier, cheaper or more safely?

Senge worked this out in personal mastery (the *fifth discipline*). In his vision all five disciplines are essential but personal mastery has a special foundational role because of the importance this discipline gives to intrinsic motivation.

Senge defined and illustrated personal mastery by relating the story of Antonio Stradivari and his quest for an exceptional musical tone that could be produced by a violin. Stradivari spent his entire life in the pursuit of that sound. He made constant refinements to the violins he crafted and produced instruments that are considered outstanding to this day. No one will ever know if Stradivari was fully satisfied with the last violin he made. Very probably Stradivari was not satisfied because of his devotion to continually trying to improve on the sound.

This way of thinking has a lot in common with the LCA vision as promoted in the world of today. Here too there should be a continuous effort towards improving the cost-effectiveness of the asset to be managed and controlled.

### 14.2.5 Team Management

Professional *team management* is considered the prime factor in creating a successful LCA-team. The LO disciplines of shared vision and mental models are indicated as essential to its achievement.

The LO approach is based on the *systems-thinking* concept described by Senge [1990]. In his vision systems thinking needs the disciplines of building a shared vision, mental models, team learning, and personal mastery to realise its potential.

This method involves breaking a problem into components, studying each part in isolation, and then drawing conclusions about the whole. In relation to the EMS this systems thinking has been elaborated and applied to the LCA-team.

*Team learning* is defined as the process of aligning and developing the capacity of a team so as to create the results its members really want. It builds on the discipline of developing a shared vision. It also builds on personal mastery. Talented teams are made up of talented individuals.

A mental model is one’s way of looking at the world. It is a framework for the cognitive processes of our mind. In other words, it determines how we think and act.

The shared vision of an organization is built up of the individual visions of its members.

Personal mastery is based on the expertise of the individual and has two essential components. First, one must define what one is trying to achieve (a goal). Secondly, one must have an accurate perception of how close one is to the goal.

In modern business management the innovative power of an organisation is becoming increasingly important. The philosophy is that the perfect things of today can probably be improved tomorrow. In this context innovation management means inspiring the organisation to continuously learn new skills. In their opinion, clear objectives and a company vision are indispensable ingredients in the inspiration of the organisation.

A learning organisation demands more than motivated actors (teams or employees) who do their jobs correctly with loyalty to the organisation. It demands actors who are 100% involved with their jobs and who pro-actively participate in improvement processes. To achieve this, it is vital that all concerned are aware of the corporate aim and vision so that they have a mutual target.

Summarising, in accordance with Garvin [1993] the following training requirements have been defined:

- Team members will be trained to keep an open mind and a non-defensive attitude in communication.
- They recognise strained relations and are capable of dealing with conflict situations.

- They know how to increase their commitment to the team values and are respectful of other team members.
- They can handle stress situations.
- They can see problems from different angles and are challenged into finding solutions.
- They can motivate and inspire their environment because they have the skills to negotiate and to advise effectively.

## 14.3 Survey of Management Tools

### 14.3.1 An Overview of LCA Related Management Tools

A large number of management tools are used in companies to support business development. Many of these are useful or even essential to work successfully with life cycle methods. Below several of the most relevant are described and positioned in relation to the EMS domain in the Methods and Techniques mapping method.

The tools described here are fall into several categories:

A. General logistics management and business planning:
- Integrated Logistics Support (ILS).
- Product Data Management (PDM).
- Enterprise Resource Planning (ERP).

B. Improvement and control of the economy:
- Life Cycle Cost Management (LCCM).
- Life Cycle Cost Analysis (LCCA).
- Design To Cost (DTC).
- Activity Based Costing (ABC).

C. Supporting the production:
- Total Productive Maintenance (TPM).

D. Assessment and Improvement of the organisation:
- Total Quality Management (TQM).
- Business Process Re-engineering (BPR).
- Balance Score Card (BSC).

E. Personnel development:
- Human Resource Management (HRM).
- Team management.
- Learning Organisation (LO).

**Tool 1** | **Integrated Logistics Support (ILS)**

### Integrated Logistics Support (ILS)

*ILS* is a common, well-known abbreviation for *Integrated Logistics Support*. The *Logistics Support* helps, supports, the logistic processes. *Integrated* refers to the fact that the support of design, production, exploitation and phase-out are integrated.

ILS is useful over the entire life cycle. It is capable of supporting the management activities: policy determination, planning, organising and directing. It is a disciplined planning and organising approach to optimise the cost-effectiveness of a technical system. It considers all support elements as influencing system design and determines the support requirements needed to provide supportable and supported equipment.

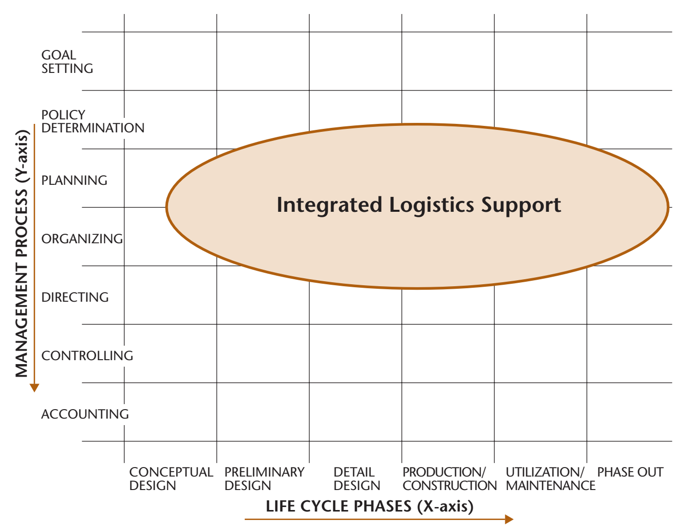



**Figure 14.4** *ILS service area.*

## Tool 2 Product Data Management (PDM)

### Product Data Management (PDM)

*Product Data Management (PDM)* is the management of all product data from conception through design, engineering, manufacturing, use and maintenance to disposal [Cornelissen, et al., 1995].

The PDM method is seen to be useful during the whole life cycle. It supports primarily the management activities: planning, organising, directing and controlling. PDM systems provide access and security control, maintain relationships among product data items, define rules that describe data flows/processes and notification/messaging facilities. PDM systems are used by managers, engineers, administrators and end-users.

The Product Data Management includes several functions that have to be structured in a logical sequence. Some elements, such as Configuration Management, Data Management and Document Management correspond to those of the ILS standard.

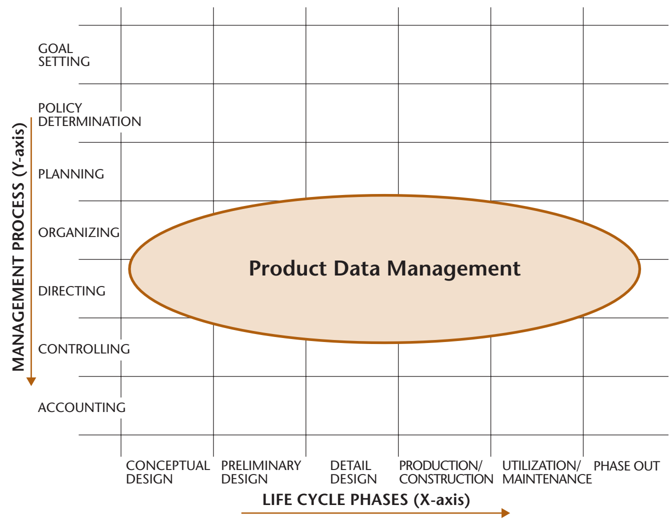



**Figure 14.5** *PDM service area.*

## Tool 3 Enterprise Resource Planning (ERP)

### Enterprise Resource Planning (ERP)

Over the last 25-30 years there has been a steady evolution of manufacturing methods. In the seventies, *Material Requirements Planning (MRP)* introduced a new mechanism to calculate more efficiently what materials were needed, when they were needed and what the optimal quantities were.

Many companies still do not have effective MRP systems in place or do not use MRP effectively. Many new business applications were developed using MRP methods as a basis, although the MRP developers often failed to consider other important factors, such as capacity, space, capital, engineering changes, and cost.

MRP eventually evolved into *Manufacturing Resource Planning (MRP II)*. Although MRP II had been the logical step towards efficient production and materials planning, companies quickly realised that profitability and customer satisfaction needed to be incorporated into the picture. This generated the need for integrated capabilities such as finance, forecasting, sales order processing, sales analysis and local and global distribution, quality control, and powerful reporting and monitoring tools. The newly developed method of this totally integrated enterprise is called *Enterprise Resource Planning (ERP)*.

ERP is expanding to include the management of every value chain operation in order to minimise the cost and time of getting products to customers. This is usually referred to in the industry as *Supply Chain Management (SCM)* or, more recently, Global Supply Chain Management. An important element in this evolution is the *Web-enablement* of Supply Chain Management Software.

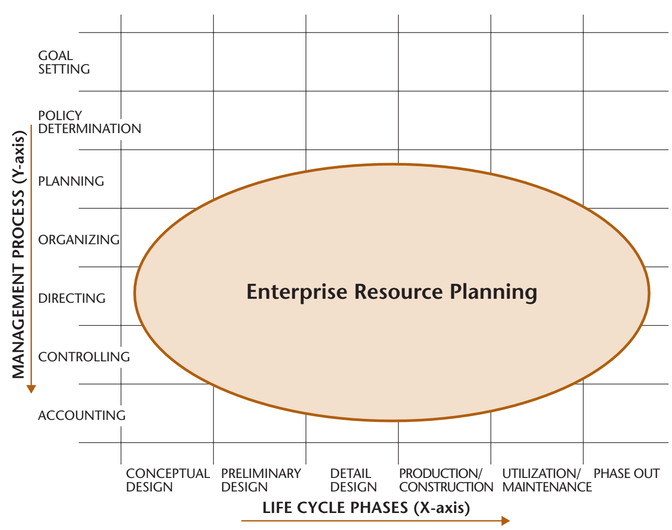



**Figure 14.6** *ERP service area.*

| Tool 4 | Life Cycle Cost Management (LCCM) |
|---|---|

## Life Cycle Cost Management (LCCM)

*Life Cycle Cost Management (LCCM)* is defined as a management method comprising the following tools [Blanchard, 1992]:

*Life Cycle Cost Analysis (LCCA)* [Blanchard, 1992], is accomplished throughout the design process by means of the evaluation of alternatives, to ensure that the selected approach reflects economic considerations. Alternative technology applications, operational concepts, support policies, level of repair, diagnostic routines and so on, are evaluated through a life cycle cost analysis. For each of the alternatives the cost is calculated and compared to the other alternatives.

*Design To Cost (DTC)* is a design approach that focuses on the system in relation to its research and development, production, operation/maintenance and disposal processes. From this point of view it is very similar to Target Costing and Kaizen Costing. Target Costing aims at the design and realisation of a cost-effective production line while Kaizen Costing aims at a cost-effective operation of the production processes. DTC aims to optimise the cost-effectiveness by reflecting life cycle cost considerations in every stage of the design process.

*Activity Based Costing (ABC)* is a method for the detailing and assignment of costs to the activities that cause them to occur [Blanchard and Fabrycky, 1998]. The objective is the *traceability* of all applicable costs to the process/activity that generates them. The ABC method makes initial allocation and later assessment of costs by function possible. It was developed to deal with shortcomings in the traditional management accounting structure where large overhead factors are assigned to all elements of the enterprise across the board, regardless of whether they directly apply.

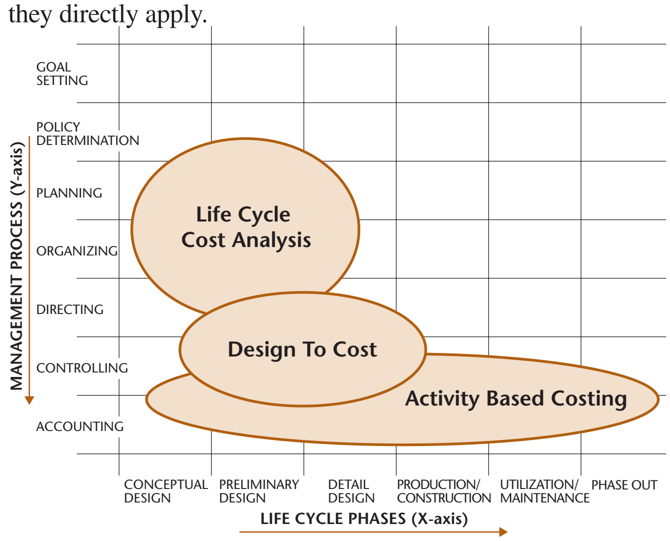



**Figure 14.7** *LCCA, DTC and ABC service areas.*

| Tool 5 | Total Productive Maintenance (TPM) |
|---|---|

## Total Productive Maintenance (TPM)

The *Total Productive Maintenance (TPM)* method is seen to be useful in the utilization/maintenance phase particularly. It can directly support the management activities: planning, organising, directing, controlling and accounting. TPM is, in essence, a method for improving the overall effectiveness and efficiency of production processes seen as a system.

Although the TPM method was initially motivated by maintenance, it does have opportunities to work for the entire logistics organisation seen as a system. From that point of view TPM´s goals and objectives are consistent with the methods and principles of ILS and LCM.

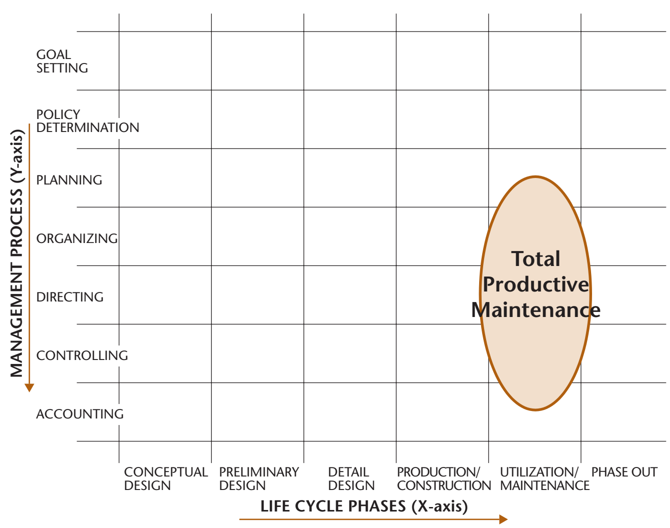



**Figure 14.8** *TPM service area.*

## Tool 6 Total Quality Management (TQM)

### Total Quality Management (TQM)

*Total Quality Management (TQM)* is both a philosophy and a set of guiding principles for the foundation of a continuously improving organisation, as pioneered by Deming and known as Deming management. TQM is the application of quantitative methods and human resources in order to improve the products and services supplied to the organisational processes and finally the degree to which the customer needs are met, both now and in the future. TQM integrates fundamental management techniques, existing improvement efforts and technical tools under a disciplined approach focused on *continuous improvement*.

The TQM method is seen to be useful over the asset life cycle. It is considered to be capable to support all management activities.

*Total customer satisfaction* is the primary objective, in contrast to the practice of accomplishing as little as possible to conform with minimum requirements. The emphasis is placed on the iterative practice of continuous improvement, seeking improvement on a day-to-day basis, as compared to the often-imposed last-minute effort initiated to force compliance with a standard. The Japanese version of this method, known as *Kaizen*, is well known in the literature [Imai, 1997].

TQM emphasises a total organisational approach, involving every group in the organisation, not just the quality control group. Individual employees are motivated from within and are recognised as being key contributors to meet TQM objectives.

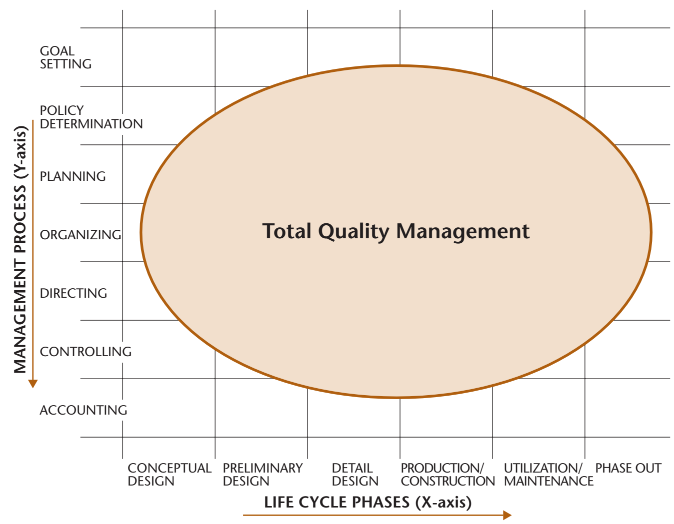



**Figure 14.9** *TQM service area.*

## Tool 7 Business Process Re-engineering (BPR)

### Business Process Re-engineering (BPR)

*Business Process Re-engineering* or *Re-design (BPR)* stands for effecting changes in business processes without affecting normal production. BPR is about completely re-thinking processes without too much analysis of the old version (for fear of limiting the breadth of the redesign). BPR is high-risk, but can also bring very high rewards.

The BPR method is seen to be useful over the entire life cycle. It is considered to be capable of supporting the management activities: policy determination, planning and organising.

BPR is driven by a business vision which encompasses specific business objectives such as cost reduction, time reduction, output quality improvement, continuous learning and empowerment [Hammer, 1990 and Senge, 1990].

BPR was essentially driven by the senior managements strategic planning process. It was viewed as a vehicle to realign strategy, operations, and systems thereby significantly improving financial results.

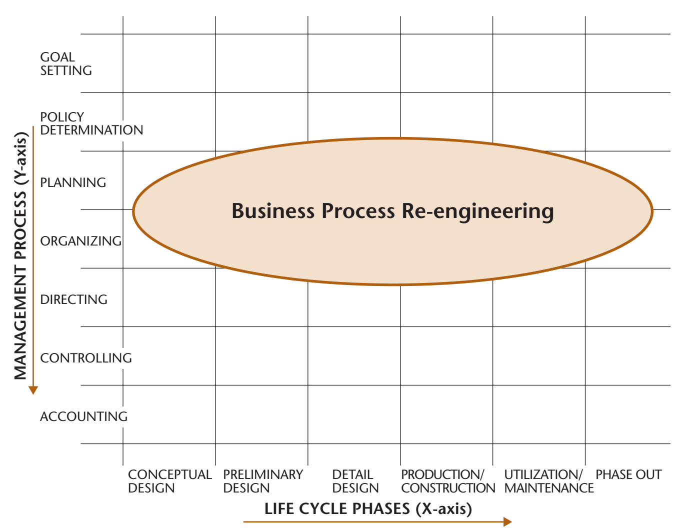



**Figure 14.10** *BPR service area.*

## Tool 8 Balanced Score Card (BSC)

### Balanced Score Card (BSC)

The *Balanced Score Card (BSC)* is an approach to management introduced in the private sector by Robert Kaplan and David Norton in the 1990's [Kaplan and Norton, 1992]. After many years of experience they realised that the traditional financial indicators used in the industrial era could no longer guide organisations into the future. According to their theory, the financial indicator is only aimed at one organisational aspect. Despite its importance, the total concentration on just the one aspect causes managerial *myopia*.

The BSC is seen to be useful over the entire life cycle and capable of supporting all management activities.

The BSC promotes the translation of an organisations mission, vision and strategy into a few performance measures that enable managers to have a fast, but comprehensive, view of the organisation position toward their desired end-state (vision). As Kaplan says, "The BSC is like the dials in an aeroplane cockpit: it gives managers complex information at a glance".

In essence, BSC focuses performance measurement in four perspectives: customer, financial accountability, internal processes, and learning and growth. The traditional financial measure is balanced with the three sets of operational measures: customer, internal processes, and learning and growth.

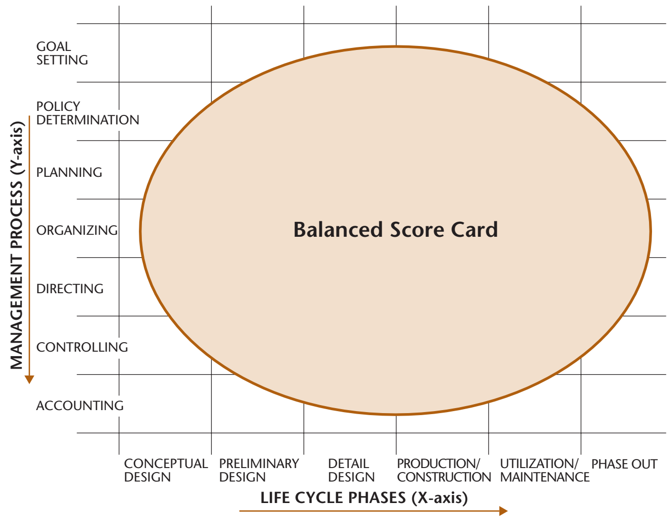



**Figure 14.11** *BSC service area.*

## Tool 9 Human Resource Management (HRM)

### Human Resource Management (HRM)

One of the most critical determinants of an organisations success in (global) ventures is the effective management of its human resources. The primary objective of HRM is a well-educated and trained work force that is motivated by a high degree of commitment and mutuality.

The primary emphasis will be placed on managerial level employees, although technical and professional employee issues will be included as appropriate due to the increasing requirements of the transfer of technology [Cascio, 1992].

*Human Resource Management (HRM)* is seen to be useful over the entire life cycle. It is considered to be capable to support all management activities.

HRM is a method concerning the whole organisation. It is a widely developed method including many specific methods and techniques in economic, social, physical, pedagogical and technological fields of interest. The method is in a rapid development stage and will get more and more attention from modern management.

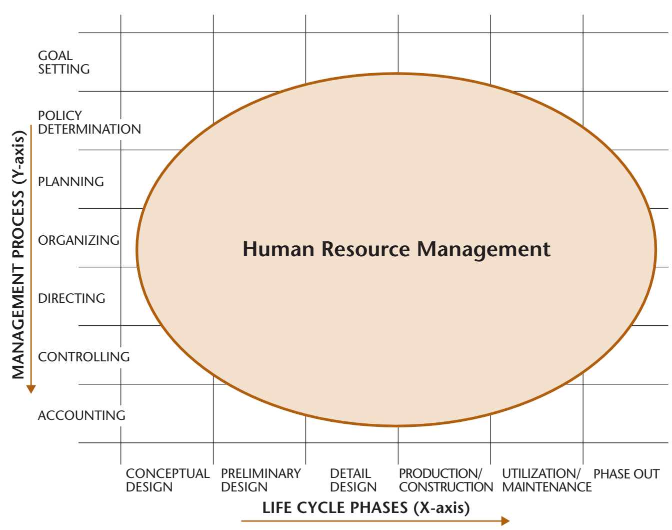



**Figure 14.12** *HRM service area.*

## Study Questions

1. Explain how to set-up a logical M&T overview for an average sized Oil Platform with about 100 men personnel, seen over the whole life cycle?
2. Explain why ILS is an essential method to get a well founded ERP and TQM?
3. Which type of organization will fit with TPM?
4. What are the interfaces between BSC and HRM?
5. How to set-up a cost/benefit analysis for implementing a PDM system?

## Abbreviations

| | |
|---|---|
| ABC | Activity Based Costing. |
| ASP | Active Server Pages. |
| BPR | Business Process Re-engineering. |
| BSC | Balance Score Card. |
| DTC | Design To Cost. |
| EMS | Environmental Management System. |
| ERP | Enterprise Resource Planning. |
| HRM | Human Resource Management. |
| ILS | Integrated Logistics Support. |
| LCCA | Life Cycle Cost Analysis. |
| LCCM | Life Cycle Cost Management. |
| LCI | Life Cycle Inventory. |
| LCM | Life Cycle Management. |
| LO | Learning Organisation. |
| M&T | Methods and Techniques Mapping. |
| MRP | Material Requirements Planning *or* Manufacturing Resource Planning. |
| PDM | Product Data Management. |
| SCM | Supply Chain Management. |
| TPM | Total Productive Maintenance. |
| TQM | Total Quality Management. |

## Internet Resources

The Deming Forum
http://www.deming.org.uk

John Stark Associates – Product Lifecycle Management (Product Data Management)
http://www.johnstark.com/epwld.html

ERPfans – Enterprise Resource Planning (ERP)
http://www.erpfans.com/erpfans/erpdefinition/erp001.html

DM Lambert, MC Cooper – Industrial Marketing Management, 2000 (Issues in Supply Chain Management)
http://hermanland.com:8080/blog/blog1/files/doc/issues_in_SCM.pdf

National Institute of Standards and Technology – Life-Cycle Cost Analysis (LCCA)
http://www.wbdg.org/design/lcca.php

Activity-Based Costing (ABC), by Narcyz Roztocki
http://www.pitt.edu/~roztocki/abc/abc.htm

Plant Maintenance Resource Center – Total Productive Maintenance (TPM)
http://www.plant-maintenance.com/articles/tpm_intro.shtml

Total Quality Management (TQM), by Dexter Hansen
http://home.att.net/~iso9k1/tqm/tqm.html

Netlib and Baruch College, City University of New York – Business Process Re-engineering
http://www.netlib.com/bpr1.shtml

The Balanced Scorecard, by Arthur M. Schneiderman
http://www.schneiderman.com/Concepts/Scorecard/scorecard.htm

Human Resources Management, by Carter McNamara,
http://www.managementhelp.org/hr_mgmnt/hr_mgmnt.htm

# 15 Product-related Environmental Policies

## 15.1 The Background

### 15.1.1 Environmental Problems

Throughout this book we have seen how product flows give rise to environmental impacts. Following the MET model the three broad categories of impacts are 1) depletion of material resources (M) 2) deterioration of ecosystems (E), and 3) adverse effects on human health through toxicity (T).

The major causes of these impacts have also been identified. A special place is occupied by the *energy sector* and the fossil fuels, since combustion of fossils – coal, oil and gas – gives rise to impacts in all categories. These include the 1) depletion of non-renewable resources, 2) deterioration of ecosystems e.g. through the acidification that the sulphur in fossils gives rise to, and 3) emissions of toxic substances such as $NO_x$, VOC, and some heavy metals, especially mercury. These impacts occur on all scales. The $CO_2$ emitted contribute to the greenhouse effect on a global scale. Air pollutants are mostly regional, e.g. affecting the Baltic Sea region, while some pollutants, such as $NO_x$, are more serious on the local level.

In addition to the energy sector we should mention the *transport sector*, which is becoming an increasingly larger part of the environmental problems due to its use of fossil fuels, the resulting air pollution, as well as impacts caused by a large infrastructure. Finally *agriculture* has a special role since it leads to a different impact panorama, with eutrophication of waters caused by artificial fertilisers, sometimes dissemination of biocides causing eco-toxic effects, and space intrusion influencing biodiversity.

### 15.1.2 The Products

The life cycle of products are contributing to environmental impacts in all these aspects, material flows, energy consumption and toxicity. Product developers can prevent or reduce environmental problems by being very careful with regard to their choice and amount of materials used for the product or service, the energy consumption of the product and to avoid toxic substances, as has been described in some detail in previous chapters.

Materials can be saved by not making products too heavy, by extending their lifetime or by promoting recycling. Wasting products constitutes in itself a resource flow. Still about 50% of all waste in Europe ends up on the landfill, and very little is reused or recycled. There are reasons to believe that re-

**In this Chapter**

cycling properties of products will be increasingly important. This gives rise to a demand for secondary materials and results immediately in reduced use of virgin material.

All products cause energy use during their production. For some products this is trivial compared to the energy use during the use phase. One important and common role of LCA is to find out where the major energy use occurs. The ecodesign strategies can be efficient tools to make changes to reduce energy use. So far energy is too cheap for it to have a very decisive impact on products for the customers, but with increasing costs this important aspect of product design will carry larger weight.

All products are transported and thus contribute to transporting environmental impacts. Most often the transport is less than 5% of the cost of a product. There is thus at present little incentive to reduce transports. It is more important that products become available when the customer or the market wants them. Thus again we will most likely not see large efforts to reduce impact from transport until it becomes more expensive.

It is important that at the start of each product development project a careful assessment be made to determine the most relevant environmental priorities to apply to the specific type of product. Also services are part of the product flows, since they all are dependent on some kind of products, although sometimes it is minimal.

### 15.1.3 The Policy Instruments

The way product designers and producers manufacture, use and waste products can be influenced by policies. Those who want to implement a policy, be it an authority or a company, need tools or – as it is most often called – an *instrument* to do so. Policy instruments related to product design are many. Several of them are listed as follows in five main categories [Rydén and Strahl, 1995; Semeniene, 2003]:

Direct *regulatory instruments*. These include prohibitions, admission procedures, registration procedures, information duties, product standard and advertising rules (in some countries not all legally regulated), guarantee periods, obligations to take back, quotas of returnable products, minimum quotas of waste materials, recycling/refuse quotas, distribution restrictions, user obligations, and user benefits.

*Economic instruments*, such as product taxes and product charges, financial assistance, subsidies for ecodesign activities, deposits refunds, marketable permits, public procurement, leasing, and product liability.

*Compulsory information instruments*, such as compulsory labelling for identification of hazardous substances, directions for proper handling and disposal, energy consumption and declaration of contents.

*Voluntary information instruments*, with eco-labelling, test reports, other voluntary labelling schemes, code of conduct, quality marks, trade marks, Life Cycle Assessments declaration.

*Voluntary agreements* between authorities and companies include non-compulsory self-commitments of certain industries, mostly established through the initiatives of business organizations. Some of the agreements may develop a more or less legally binding character in time.

All these policy tools are used by the different actors on the market, the authorities, the companies and the interest organisations, NGOs. In the

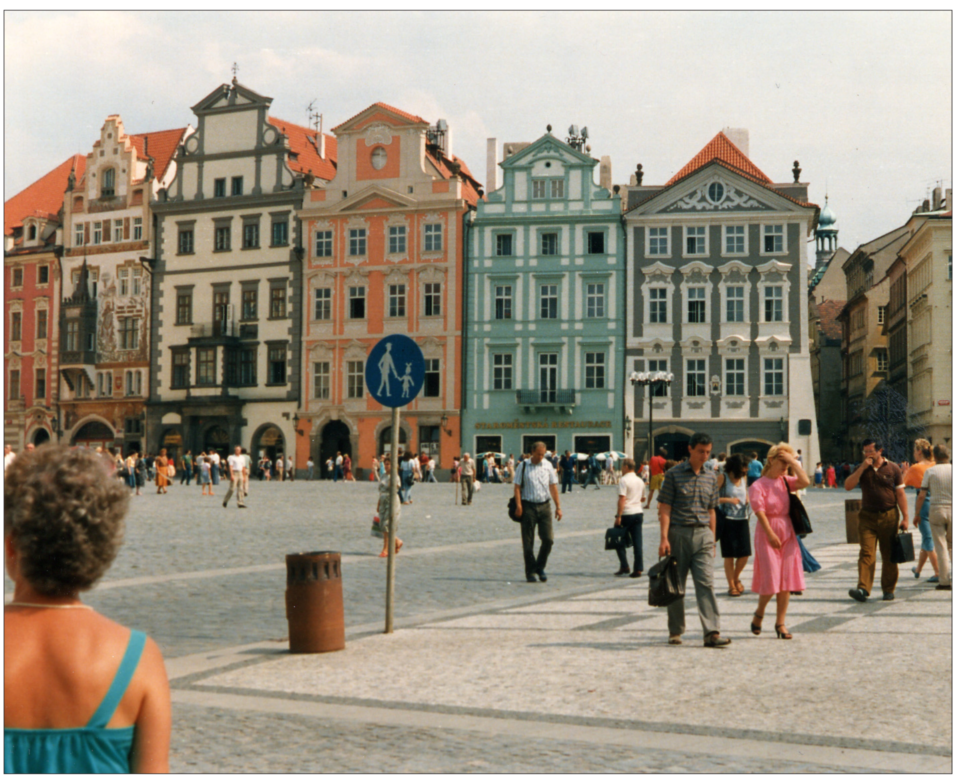


**Figure 15.1 Gdansk.** *Several cities in the Baltic Sea region improved the environmental profile substantially during the last several years. Municipal environmental policy is then crucial. Among the more successful is Gdansk city, which received the Baltic Sea prize for good water management in 2002.*

rest of the chapter this will be illustrated. For many of the examples the more detailed treatment in the previous chapters should be consulted.

## 15.2 EU Policies

### 15.2.1 The Integrated Product Policy, IPP

In February 2001, the European Commission adopted a Green Paper on an Integrated Product Policy, IPP, with the objective to "launch a debate on the role and possible measures that could be taken on a European Union level to integrate its efforts to reduce environmental impact though a product policy." (See Internet Resources *European Commission – Integrated Product Policy.*)

In the background there was a global concern about sustainable production and consumption expressed at the Johannesburg conference on Sustainable Development in 2002. At the World Summit the countries adopted a ten-year framework programme on sustainable production and consumption patterns. The main purpose of the programme was to break the link between economic growth and negative environmental impact.

The Commission wrote in 2001 that "all products cause environmental degradation in some way, whether from their manufacturing, use or disposal. The Integrated Product Policy seeks to minimise these by looking at all phases of a products' life-cycle and taking action where it is most effective."

Such a policy is not simple. The life-cycle of most products is long and complicated, from the extraction of natural resources, to manufacture, marketing, use and waste. It involves many actors, such as designers, industry, marketing people, retailers and consumers. IPP attempts to stimulate each of these to improve their environmental performance using a variety of tools, both voluntary and mandatory. These include economic instruments, substance bans, voluntary agreements, environmental labelling and product design guidelines. In addition IPP is not only an instrument to reduce the adverse effects of goods and services on the environment. It also intends to change people's attitudes to consumption and influencing the demand for products in society.

The member countries were already in 2001 charged with developing instruments and mechanisms to make IPP effective. In one member country, Sweden, the Environmental Protection Agency gathered public authorities, trade and industry and NGOs to a national network to discuss experiences and opinions on IPP. Issues that have been discussed include: the role of industry, the function of the EU internal market as an "engine" for greening products, the Swedish government's assignment on IPP, eco-labelling etc. Experiences among authorities, representatives from the environment and the business sector, scientists and consumer representatives have since jointly developed the issue to drive the process forward. (See Internet Resources *Producer responsibility at the Environmental Protection Agency*.)

### 15.2.2 EU Directives Supporting the IPP

A number of special Directives are important components of the Integrated Product Policy. Several of them will be mentioned here (see Internet Resources at the end of chapter).

The Directive 2005/32/EC concerns the ecodesign of Energy-using Products (EuP), such as electrical and electronic devices or heating equipment. This directive provides EU rules for ecodesign to reduce disparities among national regulations, in particular to reduce obstacles to intra-EU trade. The Directive defines criteria for environmentally relevant product properties, such as energy consumption, and how to introduce them quickly and efficiently, although they are not directly binding requirements for specific products. The use of such criteria will facilitate free movement of goods throughout the Union and enhance product quality and environmental protection. Products that fulfil the requirements will benefit both businesses and consumers. The Commission writes that "the Directive constitutes a breakthrough in EU product policy and introduces many innovative elements together with concrete application of the principles of the 'better regulation' package".

With the Directive the Commission implements the IPP and moves towards improving the environmental performance of energy-using products. After adoption of the Directive by the Council and the European Parliament, the Commission will be able to implement measures on specific products. These include energy consumption, waste generation, water consumption, extension of lifetime after impact assessment, and a broad consultation of interested parties. The products covered by the Directive are those with major environmental impact, large volume of trade, and a clear potential for improvement, especially if market forces fail to make progress in the absence of a legal regulations.

The Energy-using Products (EuP) Directive is expected to work together with several other EU regulations on environmental aspects of products. These are e.g. the:

- Directives regulating the management of waste from electrical and electronic equipment (WEEE).
- Directive on the use of certain hazardous substances used in this equipment (RoHS).
- Directives related to the energy efficiency of appliances such as the . Products which have been awarded the Eco-label will be considered as following these measures to the extent that the Eco-label meets the requirements of the implementing measure.

The EMAS registration is also relevant in the context. By itself an EMAS registration for a company does not grant that the products manufactured follow the Directives. A company may however use an environmental management system which includes product design, to more easily introduce compliance with the relevant Directive.

### 15.2.3 European Platform on Life Cycle Assessment

Another important initiative by the Commission to support IPP is the European Platform on Life Cycle Assessment. Its initial phase will run from 2005 to 2008. A key aspect of the project is to create a "Thematic Strategy on Waste Prevention and Recycling" and the "Thematic Strategy on the Sustainable Use of Natural Resources" as part of the Integrated Product Policy. (See Internet Resources *European Platform on Life Cycle Assessment*.)

The platform intends to support industry by reducing costs for LCA studies, to harmonise quality control, to produce consistent databases and cost-efficient data transfer in the supply chains, and to provide more reliable use of LCAs in decision support and its acceptance in governments. The guiding principles of the platform include stakeholder consensus, the use of existing LCA practice and knowledge to make it scientifically robust, practical and affordable, and long-term support.

The platform intends to also develop measures to analyse the life-cycle economy of a product through Life Cycle Cost, LCC, analysis. Life Cycle Cost is defined as the total costs of the analysed system (product, process or service) during its whole life cycle. LCC analysis should be performed at the second LCA stage, the Life Cycle Inventory, LCI. The environmental impact of the functional units should then be expressed also in monetary terms, and the modelling should be supplemented with economic inputs and outputs. The LCC should thus include costs for purchase and installation, energy, use, maintenance, environmental costs and disposal. On the positive side in such a LCC we may find incomes from energy recovery, reduced (or even eliminated) fines for pollution, lower operation and maintenance costs, etc. The LCC analysis should make it possible to identify the most cost-effective solution, resulting in a lower total cost of ownership. An LCC analysis is important from the standpoint of effective economic planning, as this includes all costs considered in the decision-making process.

The platform thus intends to establish the necessary methods and tools to enable companies to develop a both environmentally and economically optimal life cycle for a product.

### 15.2.4 Implementing the Legislation

The implementation of the regulations, European or national, is the task the national authorities. This may be done in many ways; a command and control approach is not necessarily the most efficient. However certain rules need to be respected to make the process efficient [Klemmensen, 2006].

Firstly compliance with the European environmental regulations must be harmonised between countries. This will ensure equal competition between companies in the market. First because rules are the same in the countries of origin of imported products and secondly because the rules are applied in each of the local production sectors. Trade unions, employers' associations etc all have to take responsibly for such a process.

Secondly environmental labelling and accreditation of products and services also need to be suitably promoted and controlled in order to give them credibility and prestige in the eyes of consumers.

Companies should ideally have access to the necessary technical and human means of training, research and promotion to introduce a new system. The participation of researchers and universities in seeking cleaner production processes and systems is also important. Authorities, industry associations and chambers of commerce on their own or in collaboration have traditionally contributed to such activities. Public funding is a good incentive for private companies to introduce these new systems, and a way for the authorities to foster ecological design and cleaner production.

Also, authorities need training to reinforce environmental monitoring and promotion.

The role of authorities thus should not be misunderstood. Inspection and control in many instances is more of a dialogue between authorities and companies than outright policing. In the end both parties are interested in arriving at a permit or licences which is accepted by both of them as smoothly as possible.

## 15.3 Local Authorities

### 15.3.1 The Role of Local Authorities

One of the main objectives of the local authorities is to guarantee the quality of life of citizens by preserving and improving the environment and the use of resources. It may do so by effectively using environmental regulations and economic incentives. Many of these measures are decided on at the European Union and the national level. However the local authorities have not only the task of implementing these regulations, but also, when doing so, the possibility of achieving much more in the areas of sustainable development, including product-related measures.

Most local authorities have a policy for environmental protection. Such a policy may both refer to the city's own administration and the city as such. For its own administration and activities the municipality may develop and apply manuals of good environmental practices to establish optimal use of the resources and minimal pollution and waste in public establishments.

The local authorities in most countries have many ways to improve the environmental performance on the local level. They are responsible for basic services such as water and wastewater management, energy supply and waste management. They have a planning monopoly and thus responsibility for urban planning with streets, green areas, and the built environment. They may be managing the educational systems and large part of the care of children, elderly and the primary health care. They often have a very large economic turnover in connection with these responsibilities. All of this leads to opportunities to improve product policies.

Waste management is important for organising practical recycling opportunities and organise the reuse of products which are not in bad shape. (Or even to organise repair of wasted products, which may be reused after repair.) Similarly wastewater treatment and the resulting sludge management offer opportunities for recycling.

Energy supply, which in many places is managed by municipalities, offer the possibility to reduce resource flow. First of all energy efficiency programmes have very successfully been implemented in several cities, and up to about 20% reductions have been achieved in many cases. Solid waste incineration is one way to reduce land filling and increase energy from renewable sources.

Traffic and transport planning also offers substantial practical means to reduce resource flow. A well-functioning public transport system combating increased car traffic, reduce resource flows drastically. Further possibilities include paths for biking, car-free streets, well-managed parks, arrangements for distribution of goods to the city centre.

Finally the large-scale activities in a municipality offer opportunities to buy green products. This is green procurement, to be discussed below.

### 15.3.2 Green Procurement Policies

Purchases by public authorities represent about 15% of all purchases in the European Union [Charter and Tischner, 2001]. If all these were geared by environmental concerns it would be a very strong force in promoting an environmentally improved product policy. Green procurement refers to the purchase of environment-friendly products and in general the observation of environmental criteria, for purchases in public works and projects. The EU Sixth Environmental Action Programme includes public procurement as an area which has considerable potential for "greening" the market through public purchasers using environmental performance as one of their purchase criteria.

**Figure 15.2 City environment.** *Through its planning monopoly cities play a decisive role for the environment in the cities. One important possibility is to improve the conditions for bikers and thus decrease car traffic in the city. This has been done by many cities in the Scandinavian countries and Germany, and is starting to be popular in the three Baltic states and Poland.*

There are many examples of what a local authority may do. It may, for example, request that energy for public buildings be supplied from a renewable source, or that food for a school canteen comes from organic produce. Sometimes municipalities hesitate to introduce a green procurement policy since they believe that green products are more expensive than conventional alternatives. This is true in some cases, particularly where development costs are reflected in the price; however, often there is no significant difference. The real problem may simply be that products are being ordered in small quantities, or are not available locally. Sometimes a green product may have a higher up-front purchase price, but will cost less over its lifetime. For example, a non-toxic alternative to a toxic product will cost less to transport, store, handle, and discard. Similarly, a product that uses less packaging and that is easily recyclable or reusable will carry a lower disposal cost.

Although there is a considerable amount of green procurement activity in the EU, the picture is patchy. In some Member States 90% of public authorities have defined a green purchasing policy. But although a great deal of information has been produced on green procurement, it is not always easy to find it, and in some Community languages there is virtually nothing available. As a result, authorities that would like to begin a green procurement policy often find it difficult to locate the right legal and practical information on how to proceed.

Authorities need to know what environmental information to place in their call for tenders, and what rules are used. An authority needs to respect the EC Treaty Internal Market rules and the public procurement Directives. These refer to public contracts that are covered by the EC Directives on public procurement as well as those that are not covered by these Directives but are nevertheless subject to Treaty rules. At each stage in a public procurement procedure the protection of the environment may be taken into account. For example, when defining the subject matter of a contract, public purchasers can, like private purchasers, decide to purchase environment-friendly products or services. Similarly, the public purchaser may specify the raw materials and the production processes to be used in the contract.

Since 1994 greener public procurement has been promoted in the Action Plan for a Sustainable Public Procurement Policy. In 1995 the Danish government sent a memorandum on green public procurement to all state institutions and state-owned and state-controlled companies specifying that environmental aspects must be taken into consideration alongside price and quality factors. The memorandum was been positively received and has resulted in a change in purchasing behaviour.


**Figure 15.3 Green procurement.** *For many years, Taxi 020 in Stockholm has been certified according to the standard of ISO 14001 and use an environmental management system called Green Taxi. New investments in cars is guided by green procurement and within 2010, 80% of the taxi fleet will have engines modified for ethanol, biogas or hybridtechnique. (http://www.taxi020.se)*

## 15.4 Companies

### 15.4.1 The Role of Companies

Increasingly many companies adopt environmental policies. For example one of the first measures when introducing an environmental management system is to develop an environmental policy. Such policies normally includes how the companies can promote environmental protection in their production activities. It may also outline how environmental concerns may become an opportunity for innovation rather than an obstacle to business development. An environmental policy should at best address all phases of conception, design, manufacture, distribution, use and waste processing of products and services. In the end an environmental policy should lead to environmental values becoming a fundamental part of the corporate culture of the company.

There are several reasons for a company to adopt an environmental policy. Increasingly often environmental regulation requires the introduction of practices and technologies that favour the reduction of waste and pollutant emissions and the saving of energy. These measures may also be the best step to improve the profitability and competitiveness of a company.

Authorities often support companies, that wish to revise their production systems to incorporate environmental criteria, by subsidies and tax deductions for the incorporation of cleaner technologies and those that use renewable resources. The introduction of environmental management systems is also a good platform for collaboration with inspection authorities and other authorities.

### 15.4.2 Sustainability Policies

A company policy for environmental protection may be expanded to become a policy for sustainable development. This should then include a policy for social responsibility, or so-called *corporate responsibility*.

Many companies have a long tradition of community involvement. In general the initial business response to sustainability concerns – especially those created by specific incidents such as environmental disasters – was to treat the issue as a public relations problem. However, a sustainable business also has other objectives (which some will see as being equal in importance to profitability, others as subsidiary to it). This includes environmental protection. The second is social inclusion, which can be seen as improving the stock of social capital. As economic development increasingly rests on human knowledge and skills, many would also add a fourth sustainability objective, that of enhancing the stock of human capital through education, training and other means.

This policy leads to the acceptance of some degree of responsibility for the environmental impacts of suppliers of inputs and the consumers of outputs [Russell, 1998]. Often the impacts of these upstream and downstream stages of the chain outweigh the impacts of the organization itself, particularly for service industries. In some sensitive industries, failure to identify and improve the environmental and social performance of suppliers can also compromise the saleability of the company's product or service. McDonald's and Nike are just two of the organizations that have faced consumer boycotts for allegedly failing to, respectively, conserve tropical rainforests and insist on reasonable working conditions at suppliers in developing countries.

Sustainability will be taken seriously in most companies only if a business case can be demonstrated, that is, the company needs to show the financial costs and benefits of environmental projects and measures. A great deal of work has been done on integrating environment into business financial infrastructure. It is even more difficult to include the social dimensions of sustainability. One example is Baxter Healthcare International's environmental financial statement to assess its environmental costs and benefits. The statements demonstrated that the financial benefits created by environmental programmes substantially exceed their costs.

Most companies have paid less attention to the social performance of suppliers, but this is now being addressed through new initiatives. The evidence is that concerted initiatives of this kind by business customers can drive considerable environmental and social improvement among their suppliers. This is normally expected to occur in addition to, rather than instead of, other procurement criteria such as price and quality. Further, as more procurement moves to electronic e-commerce platforms, some of the bonds between buyer and seller are broken, with the possible result that it will become more difficult to put pressure on for better – or even to assess accurately – sustainability performance.

### 15.4.3 Producer Responsibility

One step to a better product policy is when the company producing a product also has a responsibility to take care of the wasted product. This is *producer responsibility*. It is a means to transform today's consuming and polluting "waste society" into an ecologically sustainable society. It is often developed as an agreement between authorities and companies.

The long-term purpose of producer responsibility is that it should lead to more environmentally responsible product development. In this way, producer responsibility becomes an instrument to induce producers to develop products that are more resource-efficient and easier to recover/recycle and do not contain environmentally hazardous substances.

Producer responsibility is implemented by the establishment of companies or associations for the collection of wasted products, such as paper, glass, tyres, etc. It is being reported to authorities as recycling rates. It may also be implemented as refunding systems, such as refunding of returned aluminium cans or PET bottles. Then the company established by the producers then take care of the recycled bottles.

Producer responsibility has been introduced in many countries in the 1990s. In Sweden it was included in the Eco-cycle Bill of 1993, formally by amendments and addendums to the Waste Collection and Disposal Act from 1994 (see *Producer responsibility at the Environmental Protection Agency*, Internet Resources). The recovery/recycling targets agreed with the producers were reached in 2003 and surpassed for some product groups. 48% of the packaging waste was recycled and 77% was recovered. Recent reports show that maintenance of the recycling stations has improved significantly and that littering has decreased. Collection of WEEE (waste from electrical and electronic equipment) continued to be high as about 11 kg of WEEE collected per person and year. Supervision of vehicle dismantling companies is being strengthened by a combination of measures. All collected tyres are disposed of by other means than land filling.

### 15.4.4 Reporting Business Performance

Companies, that have improved their environmental performance want to make this known to customers and other partners. There are several ways to do this. It is all part of green marketing, but also important internally for the company. Environmental reporting in Europe is an increasingly compulsory activity. For companies it is important to identify the tangible benefits in reporting. There are several positive outcomes of reports, as they are directed towards several target groups.

Several different kinds of reporting exist. Some of them are listed in Table 15.1. Internal reports are needed technically for the work of the company. A good report also enhances employee morale, and encourages future cooperation and participation.

Also an eco(re)design project should at best include writing a report. The report should be based as much as possible on qualitative estimations of the environmental gains made as a result of the (re)design. It should summarise the result of the project and hopefully be able to demonstrate its advantages.

External reports are important for the external relations of a company. It is important for the company to demonstrate to external stakeholders, by strengthening stakeholder relations, and demonstrating the coherence of overall management strategy. It plays a role in the financing of a company by informing existing investors and reaching a wider range of possibly new investors.

Another target group for reporting are authorities. Effective self-regulation minimises risk of future regulatory intervention.

The public in general is an important target group. Good reporting contributes to public recognition for corporate accountability and responsibility. Potential customers and suppliers may are influenced by access to lists of "preferred suppliers" of buyers with green procurement policies.

The standard for sustainability reporting in business now developing is the Global Reporting Initiative, GRI. The manual for GRI, used by many companies, especially larger companies, address important elements in economic, environmental and social performance. One response to this has been attempts to adapt existing business performance measurement activities to take account of sustainable development. The developers of this framework argue that:

*The new, value-related measures will lead a company away from commodity products and toward a search for ways to differentiate products through branding, upgrading function, or building with services. These measures reward delivery of value to the customer – translated into sales or value added – and the simultaneous reduction in environmental footprints. The older measures, in contrast, reward increases in throughput, capital investment, and production.*

Of their six new measures, knowledge intensity and focus on function are the most challenging. The first is related to the question of measuring intellectual capital, which is attracting growing interest in conventional business performance measurement circles.

## 15.5 The Market

### 15.5.1 Green Procurement and Supply Chain Management

The environmentally responsible or "green" procurement – the selection of products and services that minimize environmental impacts – is important not only for authorities but also for companies [Brezet, 1997]. In companies this has two aspects. Firstly the company buys products and services just as a municipality may do. Secondly it is a question of buying raw materials for manufacturing. In the first case the green policy requires that the company carry out an assessment of the environmental consequences of a product at all the various stages of its life cycle. This means considering the costs of securing raw materials, and manufacturing, transporting, storing, handling, using and disposing of the product. It means evaluating purchases based on a variety of criteria, ranging from the ne-

**Table 15.1 Environmental reporting.** *Environmental reports used by different companies serves several purposes some internal and some external. Performance indicators (emissions or resource use per product or product value) and product focused reporting are the two most interesting in product development [Hillary and Jolly 2001].*

| Reporting methodology | Description |
|---|---|
| Compliance-based reporting | Reporting the level of compliance with external regulations and consent limits is often the core feature of the environmental reports of heavily regulated utility industries such as water and electricity. |
| Toxic release inventory-based reporting | Many US companies are required by law to publish lists (detailed in physical quantities) of emissions of specific toxic substances. These mandated disclosures often take precedence over voluntary performance-based disclosures. |
| Eco-balance reporting | Some companies (including many from Germany) construct a formal "eco-balance" – a detailed account of resource inputs and outputs (in terms of product output and waste/emissions) – from which they then derive performance indicators. |
| Performance-based reporting | Perhaps the most common form of environmental reporting. Reports are usually structured around the most significant areas of environmental impact. Performance improvement targets are then set and appropriate performance indicators developed and disclosed annually. |
| Environmental burden reporting | The UK chemicals company, ICI, has developed an externally focused reporting approach that quantifies the company's impact on several environmental quality measures. A potency factor allocated to each emission is multiplied by the quantity emitted per year to provide the environmental burden. |
| Product-focused reporting (ISO 14031) | Volvo has produced an "environmental product declaration" report that evaluates the total environmental effect of one specific Volvo model. Issues covered include operation, recycling, manufacturing and environmental management. In this case, environmental responsibility has extended beyond the factory gate. |

cessity of the purchase in the first place to the options available for its eventual disposal.

The environmental performance of suppliers has been the focus of a number of collective and single-company initiatives. One of the best known of these is that of the UK-based retailer of do-it-yourself (DIY) products, B&Q. In 1992 the company initiated a programme to raise the environmental awareness of its suppliers and award them a rating. More action was also taken to inform customers about the environmental implications of the products the company sells. In 1998 the company announced a further stage in its programme, with a target of all its suppliers understanding the key impacts over the life-cycles of their products and developing an action plan to deal with them.

For an organization to implement a green procurement programme, it must have commitment from all levels. A policy statement outlining the corporate commitment to green procurement or environmentally focused supply chain management is needed. It may lead to choosing other distributors or agreeing with old partners to find new products or resources. If several companies have similar policies, the improved market will support such a development. Sometimes there are technical difficulties to overcome and a project is needed to develop a new product, new ways to store a product etc. In these situations it is important that the environmental requirements be specified, best with LCA techniques.

In Canada, where considerable experience exists, the authorities write: "A pilot project can provide practical experience in purchasing green products and services, by applying green procurement principles to a specific product or service. Pilot projects can be used to generate more detailed guidance on purchasing practices. Implementing the green procurement programme will require an assignment of accountability, plus a well-designed communications plan addressing employees, customers, investors, suppliers and the public. As with all business practices, it is important that a systematic review of the green procurement programme be carried out, in order to establish whether the scheme is meeting its targets." (See *Manitoba Green Procurement Network*, Internet Resources)

Green procurement can also be applied to larger projects. In the construction industry this may be very important, such as for greening the building of houses. "Green" construction materials can be used in energy-efficient project designs. Transport often has a large share of the environmental impact, and one needs to consider vehicles with good fuel efficiency or providers that have a shorter distance to the site of construction or company.

Often however procurement in a company is concerned with the supply of resources for the production. Then it is most often referred to as *supply chain management*. This refers to the selection of resources which have reduced environmental impact, expressed e.g. as footprint or MIPS, which require less transport, and which have less impact later on in the life cycle of the product.

### 15.5.2 Selling an Environmentally Better Product

It is important that the environmentally improved product (which may often also be of superior quality) also is successful on the market. This depends on several factors.

An important variable is the price. Ideally the new improved product should not be much more expensive than the traditional product. For environment-conscious customers who change quickly to the new product, the so-called early adopters, the price difference will be less important; such customers are willing to pay more for a better environment. For the majority it is, however, an obstacle for choosing a new product. Then it is important that the advantages of the new product be clearly stated and described. The self-reported positive outcomes of consumers' own estimations of their "willingness-to-pay-more" for green products regrettably show a strong positive bias compared to their actual purchase behaviour.

But costs may also be lower. Call-a-car for example, joint leasing of cars by groups of people, and other "service products", may provide a better service, a higher quality car than the old one, at lower cost. If a product has been redesigned in such a way that the environmental costs for other parties in the chain are demonstrably lower than the costs for competitors' products, it is possible to achieve a price advantage over the competitors. Similarly, energy saving during use or a longer life may also justify a higher price.

If the new product is to achieve a high market penetration, then it is essential to ensure an intensive distribution network. If the main aspect is to improve existing products, this need not be a problem – existing distribution channels can continue to be used. The market has meanwhile developed to such an extent that chain stores are starting to sell environment-friendly products and use environment-friendly packaging.

If special arrangements are made (with recyclers or municipalities, for example) about the return or "take-back" of products, it is wise to include them in the marketing plan. Particular attention should be given to the logistics and financial aspects of the combination of product distribution and return of packaging by retailers. This also applies in the event that the company takes care of this "reverse distribution" at its own expense. By doing this, the company – in its plan – makes it clear to all concerned that it regards green marketing as more than simply selling "green" products, and also that it takes the after-sales aspect seriously.

The retail trade is a crucial link in the sale of ecodesign products. Retailers may set higher environmental requirements in order to improve their range of green products. Assuming that price and functional quality are competitive with classical products, the retail trade selects its products on the basis of e.g. packaging, low-solvent products and products that contain no CFCs or heavy metals. It is essential for companies to cooperate actively with the retail trade to be successful in ecodesign and green marketing.

## Study Questions

1. Describe the basis of the EU environmental policy on products.
2. Make an overview of EU product policy instruments. Is something missing? If you think so explain why.
3. In which way may a local authority influence the quality of the environment in the municipality through its product policy. Give examples.
4. Explain how the LCC (Life Cycle Cost) of a product is related to its LCA (Life Cycle Assessment).
5. In which ways can a producer responsibility policy be implemented?
6. Many retailers have introduced a green procurement policy. Give some examples and describe the effects.

## Abbreviations

| | |
|---|---|
| EMAS | Environmental Management and Audit Scheme. |
| GRI | Global Reporting Initiative. |
| IPP | Integrated Product Policy. |
| PET | Poly Ethylene Teraphthalate. |
| VOC | Volatile Organic Compound. |
| WEEE | Waste of Electrical and Electronic Equipment. |

## Internet Resources

European Commission – Integrated Product Policy (IPP)
http://ec.europa.eu/comm/environment/ipp/

Directive 2005/32/EC on the ecodesign of Energy-using Products (EuP)
http://europa.eu.int/comm/enterprise/eco_design/

European Platform on Life Cycle Assessment
http://ec.europa.eu/comm/environment/ipp/lca.htm

Soil and waste unit of the European Platform on Life Cycle Assessment
http://lca.jrc.it/

Environmentally Responsible Procurement – Business and Sustainable Development, BSD, A global guide
http://www.bsdglobal.com/tools/bt_green_pro.asp

Manitoba Green Procurement Network (MGPN), Canada
http://www.pws.gov.nt.ca/procurement/greenProcurement.htm

Producer responsibility at the Environmental Protection Agency, Sweden
http://www.internat.naturvardsverket.se/
*(Search for producer responsibility)*

The Global Reporting Initiative (GRI)
http://www.globalreporting.org/

Ministry of Trade and Industry, United Kingdom, on IPP
http://www.dti.gov.uk/sustainability/IPP.htm

NOF Corporation environmental policies, Japan
http://www.nof.co.jp/english/environment/kan16.html

Applied Data Systems, Inc. (ADS) Environmental policies, Md USA
http://www.applieddata.net/aboutus_environmental.asp

# Glossary of Key Terms and Definitions

**Acidification:**
lowering pH value of a soil or water with low buffering capacity, typically forest soil, due to acid rain.

**Acute Toxicity:**
effects occurring shortly after, normally upon a single exposure of a substance, which can vary from a simple flush to the death of the individual.

**Best Available Techniques (BAT):**
concept introduced in the EC directive addressing environmental performance of a bundle of activities affecting all environmental aspects of a plant's or industry's operations, such as procedures, techniques, technologies, maintenance, operating standards, de-commissioning of plants and energy and efficiency audits.

**Chapman Cycle:**
continuous flow in the stratosphere from oxygen to ozone and back to oxygen, both under the influence of UV radiation, initiated by UV radiation, often referred to as "Chapman Reactions".

**Chronic Toxicity:**
toxic action manifested as effects occurring after a longer period of continuous or repeated administration of doses lower than those causing acute effects.

**Clean Technology, Cleaner Production (CP):**
changes in use of chemicals, production technology, re-circulation schemes, etc., that reduces the volume of emissions, waste, and waste water from an industry as well as its degree of pollution.

**Continuous Acquisition and Life-cycle Support (CALS):**
the application of computerized technology to the entire spectrum of logistics. Of particular emphasis in recent years is the development and processing of data, primarily in a digital format, with the objectives of reducing preparation and processing times, eliminating redundancies, shortening the system acquisition process, and reducing overall program costs (MIL-HDBK-259).

**Control (Management):**
a compilation of management activities, including the efficient use of control instruments, to ensure that the results meet the objectives in a cost-effective manner.

**Cost Effectiveness:**
the value received for the resources expended, the ratio of cost to (system) effectiveness [Juran, 1988]. Relation of the System Effectiveness (or mission fulfilment) to Total Life Cycle Cost [Blanchard, 1992].

**Dematerialisation:**
materials management strategies to use less material through e.g., reducing equipment size and weight, increased efficiency of the flow processes or increased recycling.

**Design for the Environment (DfE):**
also called *Ecodesign* – designing a product to minimize the environmental impacts from its entire life cycle and/or make it easier to recycle.

**Dioxins:**
a structurally closely related group of hydrophobic chemicals, which are persistent and bio-accumulating, and some of them extremely toxic; Dioxins are polychlorinated dibenzo-p-dioxins (PCDDs). The closely related dibenzofurans (PCDFs) have dioxin-like properties.

**Directive:**
the most common type of EU legislation, being binding for each member state. as to the result to he achieved, referred to by official numbers, for instance 70/220/EEC, in which the first number refers to the year in which the directive was adopted the second number is a serial number, and the addition "EEC" indicates that the directive was legally based on an EEC Treaty.

**Ecodesign:**
also called *Design for the Environment* – designing a product to minimize the environmental impacts from its entire life cycle and/or make it easier to recycle.

**Eco-indicator:**
an object (element, component) of which data (attributes) related to environmental impact are recorded.

**Egalitarian:**
having or showing the belief that all people are equal and should have equal rights.

**End-of-pipe:**
technologies which remove pollutants from exhausts and emissions at the point where they leave a factory or other unit to be returned to the environment.

**Environmental Management System (EMS):**
the way in which an organization, often a company, organizes its environmental work and the relations between management, the day-to-day operations and its environmental problems.

**Environmental Policy:**
the response of societies to environmental problems, consisting of political decisions on environmental protection, through legal and economic means and other policy measures, such as education, and on all levels – local, national, international as well as global.

**Halogenated Organic Compounds, Hydrocarbons:**
organic compounds in which at least a part of hydrogen atoms are replaced by fluorine, bromine or chlorine, as a means to make the compounds more stable.

**Hierarchist:**
the individual belongs to a group of people in an organisation who have power or control.

**Implementation:**
realisation or accomplishment of a policy.

**Individualist:**
a person who is noticeably independent and individual in opinions and/or style.

**Input-output Models:**
models based on transaction tables, usually quite large with rows representing each plant/activity input and columns representing each plant/activity output. The transaction tables are considered as inventory analyses under the LCA structure. The models, if properly applied, will identify trends that may be useful in determining system impacts on the environment.

**Learning Organization (LO):**
an organization skilled at creating, acquiring and transferring knowledge and at modifying its behaviour to reflect new knowledge and insights [Senge, 1990].

**Life Cycle Assessment (LCA):**
a systematic method for assessing the environmental impacts associated with a product or service system to:
a) build an inventory of inputs and outputs;
b) make a qualitative and quantitative evaluation of those inputs and outputs;
c) to identify the most significant aspects of the system relative to the objectives of the study [ISO 14000].

**Life Cycle Inventory (LCI):**
the identification and qualification of the material and resource inputs and emission and product outputs from the product/unit processes in the life cycle of a product system.

**Life Cycle Management (LCM):**
an asset management approach to manage a capital asset, seen as a (complex) system, by functions, with the aim of achieving the required system effectiveness for the estimated (minimum) costs throughout the asset life cycle [Stavenuiter, 2002].

**Management Tool:**
procedure to decide which solution is the best for addressing a specified environmental problem.

**Material Flows Analysis:**
reporting of materials use to monitor environmental impact and economic development, developed at the Wuppertal Institute in Germany, under the leadership of F. Schmidt-Bleek, to a useful measure of sustainability.

**Nutrients:**
organic and inorganic chemical compounds or elements necessary in various amounts to support normal living processes.

**PolyChlorinated Biphenyl (PCB):**
a group of organochlorine compounds which are among the most toxic environmental pollutants, produced by chlorination of biphenyl, a molecule consisting of two benzene rings joined by a carbon-carbon bond.

**Polycyclic Aromatic Hydrocarbons (PAH):**
group of organic pollutants, often with toxic, carcinogenic or mutagenic features, characterized by two or several unsaturated and fused ring systems.

**Recycling of Waste:**
the reuse of waste, e.g. use of paper for new paper products or sludge for fertilizer in agriculture.

**Resource Management:**
use of natural resources, in particular the basic resources of water, air, soil, and energy; a main concern for environmental engineering.

**Sustainable Development:**
the 1987 Brundtland report *Our Common Future* defined sustainable development as development "that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development focuses on good management and use of (renewable) resources, and the reduction of environmental impact, taking into account environmental, social and economic aspects.

**System(s):**
a nucleus of elements combined in such a manner as to accomplish a function in response to an identified need. A system may vary in form, fit and structure. When appropriate, systems can be distinguished from each other by the use of a prefix e.g. "technical" systems (specifically used for capital assets), "organizational" systems, "information" systems, "management" systems, "accounting" systems, etc. [Blanchard and Fabrycky, 1998].

**Total Productive Maintenance (TPM):**
a Japanese concept involving an integrated, top-down, system life cycle approach to maintenance with the objective of maximizing productivity. It is based on the principle that equipment improvement must involve everyone in the organization, from operators to top management [Nakajiima, 1989].

**Toxicity:**
the capability of a chemical to cause toxic effects in living organisms.

**Waste Management:**
strategies and methods to reuse, recycle or get rid of refuse; today a main goal is to treat waste in a way which could save as much resources as possible.

# References


Adriaanse, A.S.; Bringezu, S.; Hammond, A.; Moriguchi, Y.; Rodenburg, E.; Rogich, D. and Schütz, H. (1997). *Resource Flows: The Material Basis of Industrial Economies.* World Resources Institute: Washington D.C.

Altvater, E. (1985). Lebensgrundlage (Natur) und Lebensunterhalt (Arbeit). *WZB Papers*. Wissenschaftszentrum Berlin, Free University of Berlin: Berlin.

Andersson, A. (2003). Soil protection and solid waste management. In *Environmental Science*, Rydén, L.; Migula, P. and Andersson, M. (eds.). Baltic University Press: Uppsala, Sweden.

AtKisson, A. (1999). *Beleiving Cassandra*, Chelsea Green Publishing: White River Junction, Vt USA.

Azar, C.; Holmberg, J. and Karlsson, S. (2002). *Decoupling – past trends and prospects for the future*. Swedish Ministry of Environment: Stockholm.

Baumann, H. and Tillman, A-M. (2004). *The Hitch Hiker's Guide to LCA. An Orientation in Life Cycle Assessment Methodology and Application*. Studentlitteratur: Lund, Sweden.

Berg, P. G. (1997). In *Community Development – Approaches to sustainable habitation. A Sustainable Baltic Region, Session 7,* Andersson, H.; Berg, P. G. and Rydén, L. (eds.). Baltic University Programme, Uppsala University: Uppsala, Sweden.

Blanchard, B.S. (1992). *Logistics Engineering and Management*. Prentice Hall: Upper Saddle River, USA.

Blanchard, B.S. and Fabrycky, W.J. (1998). *Systems Engineering and Analysis*. Prentice Hall: Upper Saddle River, USA.

Blonk, T.J; Davidson, M.D. and Lafleur, M.C.C. (1997). *Feasibility of Operationalisation of Depletion of Abiotic Resources in LCA via the Key Resources Energy and Land*. IVAM Environmental Research, University of Amsterdam: Amsterdam.

Bourgonje, G.C.J. et al. (1995). *Technisch Documenteren*. Ten Hagen and Stam: The Hague (in Dutch).

Bringezu. S. and Schütz, H. (2001). *Material use indicators for the European Union, 1980-1997.* Eurostat Working Papers 2/2001/B/2: Luxembourg.

Brezet, H. and Van Hemel, C.G. (1997). *Eco-design*, *A promising approach to sustainable production and consumption*. UNEP: Paris.

Campbell, (1998). *A Guide to Determining the World's Endowement and Deplation of Oil*. Petroland Consultants. (http://www.hubbertpeak.com)

Carlsson, R.; Löfgren, G. and Steen, B. (1995). *SPINE: A relational database for life cycle assessment*. IVL Report B1227. The Swedish Environmental Research Institute: Gothenburg.

Carlsson, R. and Pålsson, A-C. (1998). *Establishment of CPM's LCA database*. CPM Report 1998:3. Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology: Gothenburg.

Carlson, R. and Pålsson, A-C. (1999). *A procedural approach to the design of a model of a technical system (under preparation), CPM*. Chalmers University of Technology: Gothenburg, Sweden.

Cascio, W.F. (1992). *Managing human resources: Productivity, quality of work life, profits*. McGraw-Hill: New York.

Cekanavicius, L. and Semeniene, D. (2003). The cost of pollution – environmental economics. In *Environmental Science*, Rydén, L.; Migula, P. and Andersson, M. (eds.). Baltic University Press: Uppsala, Sweden.

Chapman, P. F. and Roberts, F. (1983). *Metal Resources and Energy*. Butterworths Monographs in Materials: Boston.

Charter, M. (2001). Eco-design and supply chain management a guide for environmental managers, purchasing managers & product designers. In *Sustainable Solutions Developing Products and Services for the Future*, Charter, M. and Tischner, U. (eds.). Greenleaf-publishing: London.

Charter, M. and Tischner, U. (2001). *Sustainable Solutions – Developing Products and Services for the Future.* Greenleaf-publishing: London.

Christiansen, K. (ed.) (1997). *Simplifying LCA: Just a Cut?* SETAC EUROPE LCA Screening and Streamlining Working Group. Final report, March 1997. SETAC: Brussels.

Clift, R. (1995). The Challenge for manufacturing – Rapporteur's Summary. In *Engineering for Sustainable Development*, McQuaid, J. (ed). The Royal Academy of Engineering: London.

Clift, R. (1997). Clean Technology – The idea and the practice. *Journal of Chemical Technology and Biotechnology*, vol. 68, pp. 347-350.

Cornelissen. M.; de Kok, A. and Mandemaker, D. (1995). *PDM Selection Guide. From needs to selection; a business solution*. Delft University Press: Delft, The Netherlands.

Cowell, S.J.; Hogan, S. and Clift, R. (1997). *Positioning and applications of LCA*. LCANET Theme report. Centre for Environmental Strategy, University of Surrey: UK.

Cramer, J.; Quakernaat, J. and Dokter, T. (1993). *Theory and practice of integrated chain management*. TNO Apeldoorn: The Netherlands.

Daly, H.E. (1991). *Steady State Economics*. Covelo: Washington, D.C.

Daly, H.E. (1996). *Beyond Growth. The Economics of Sustainable Development*. Beacon Press: Boston.

Daly, H.E. (2001). Unwirtschaftliches Wachstum und Globalisierung in einer vollen Welt. *Natur und Kultur* **2**, 2, pp. 3-22.

Davis, G.B. and Olson, M.H. (1985). *Management Information Systems: Conceptual foundations, structure and development*. McGraw-Hill: New York.

De Leeuw, A.C.J. (1997). *Organisaties: Management, Analyse, Ontwerp en Verandering; een Systeemvisie*. Van Gorcum: Assen, The Netherlands (in Dutch).

De Smet, B.; Hemming, C.; Baumann, H.; Cowell, S.; Pesso, C.; Sund, L.; Markovic, V.; Moilanen, T. and Postlethwait. D. (1996). *Life Cycle Assessment and Conceptually Related Programmes*. Draft Document. Unpublished report of SETAC conceptually related programmes working Group: Leiden, The Netherlands.

Deffeyes, K. (1964). *Uranium Distribution in Mined Deposits and in the Earth Crust*. Department of Energy: Grand Junction Colorado, UK.

*Design for Environment (DfE) Guide* (2003). Industrial Research Assistance Program of the National Research Council of Canada: Ottawa. (http://dfe-sce.nrc-cnrc.gc.ca/home_e.html) The guide is based on the original promise manual.

Doig, A.; O'Brien, M. and Clift, R. (1996). Social and environmental Life Cycle Assessment: Approach and methodological development. *International Journal of Life Cycle Assessment* **1**, 4, pp. 1-7.

Druckner, P. (2002). *Management in turbulent times*, Harper Perennial: New York.

Döppe, T.; Giljum, S.; Hammer, M.; Hinterberger, F.; Luks, F.; Schnepf, D. and Spangenberg, J.H. (2003). *Freier Handel, nachhaltiger Handel – ein Widerspruch? Hintergrundpapier für die Debatte um Handel und nachhaltige Entwicklung nach Johannesburg*. Heinrich-Böll-Stiftung: Berlin.

*Eco-indicator 99* (1999). *Manual for Designers*. Ministry of Housing, Spatial Planning and the Environment: The Hague.

Eriksson, O.; Frostell, B.; Björklund, A.; Assefa, G.; Sundqvist, J-O.; Granath, J.; Carlsson, M.; Baky, A. and Tyselius, L. (2002). ORWARE – A Simulation Tool for Waste Management. *Resources, Conservation and Recycling* **26**, pp. 287-307.

Fischer-Kowalski, M. and Haberl, H. (1997). Tons, Joules, and Money: Modes of Production and Their Sustainability Problems. *Society & Natural Resources* **10**, 1, pp. 61-85.

Frankl, P. and Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. (Contributing authors: Bartolomeo, M.; Baumann, H.; Beckman, T.; Von Dänicken, A.; Frankl, P.; Leone, F.; Meier, U.; Mirulla, R.; Rubik F. and Wolff, R.) Springer Verlag: Berlin, Germany.

Frischknecht (1997). *Goal and Scope Definition and Inventory Analysis*. LCANET Theme report, ETH: Zürich, Switzerland.

Garvin, D.A. (1993). Building a learning organisation. *Harvard Business Review*, July-August, pp. 78–91.

Giddings, B.; Hopwood, B. and 0'Brien, G. (2002). Environment, economy and society: fitting them together into sustainable development. *Sustainable Development* **10**, 4, pp. 187-196.

Goedkoop, M. (1995). *The Eco-indicator 95* (NOH report 9514). Pré Consultants: Amersfoort, The Netherlands.

Goedkoop, M. and Oele, M. (2001). *User Manual. Introduction into LCA methodology and practice with SimaPro 5*, Pré Consultants: Amersfoort, The Netherlands.

Goedkoop, M. and Spriensma, R. (1999). *The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Methodology Report*. Pré Consultants: Ameersfort, The Netherlands.

Grober, U. (2002). Tiefe Wurzeln: Eine kleine Begriffsgeschichte von "sustainable development" – Nachhaltigkeit. *Natur und Kultur* **3**, 1, pp. 116-128.

Hammer, M. (1990). Reengineering work: Don't automate, obliterate. *Harvard Business Review*. July/August 1990, pp. 104-112. Harvard Business School Publishing: Boston.

Harrison, P. (1992). *The Third Revolution: Environment, Population and a Sustainable World*. IB Tauris & Co: London.

Hauschild, M.Z. and Wenzel, H. (1998). *Environmental assessment of products. Volume 2: Scientific background.* Chapman and Hall: London, UK.

Heijungs, R.; Huppes, G.; Udo de Haes, H.; Van den Berg, N.W. and Dutilh, C.E. (1996). *Life cycle assessment. What it is and how to do it*. Centre of Environmental Science, Leiden, The Netherlands. UNEP: Paris.

Hemel, C. and Brezet, H. (1997). *Handleiding voor Ecodesign*. UNEP/TUDelft: Delft, The Netherlands (in Dutch).

Hillary, R. (1995). *Life Cycle Assessment*. Centre for Environmental Technology, Imperial College of Science and Technology: Great Britain.

Hillary, R. and Jolly, A. (2001). *The CBI environmental management handbook: challenges for business*. Confederation of British Industry. Earthscan Publications: London.

Hinterberger, F. and Stewen, M. (2001). *Zur Notwendigkeit und Umsetzungsproblematik langfristiger Umweltziele – eine evolutorisch-institutionalistische Sicht.* Symposium in Schloß Wartensee/St. Gallen, Switzerland. Verein für Sozialpolitik: Cologue, Germany.

Holmberg, J.; Robèrt, C-H. and Eriksson, K-E. (1994). *Socio-ecological principles for a sustainable society*, Report 94-11. Department of Physical Resource Theory, Chalmers University of Technology: Gothenburg, Sweden.

Imai, M. (1997). *Gemba Kaizen: a commonsense low-cost approach to management*. McGraw-Hill: Berkely, California, USA.

ISO 14040 (1997). *Environmental Management – Life Cycle Assessment – Principles and framework*. International Organisation for standardisation: Geneva, Switzerland.

ISO/TS 14048 (2002). *Environmental Management – Life Cycle Assessment – Data Documentation Format*. International Organisation for Standardization: Geneva, Switzerland.

Jackson, T. (2002). Paradies-Verbraucher? Aufstieg und Fall der Konsumgesellschaft. *Natur und Kultur* **3**, 2, pp. 55-74.

James, P. (1996). *Total Quality Management – An Introductory Text*, Prentice Hall.

Jensen, A.A. et al. (1997). *Life Cycle Assessment (LCA): A guide to approaches, experiences and information sources.* Report to the European Environment Agency. EIA: Copenhagen, Denmark.

Jones, J.V. (1995). *Integrated Logistics Support Handbook*. McGraw-Hill: New York.

Juran, J.M. and Blanton, G.A. (1999). *Juran's Quality Control Handbook*. McGraw-Hill: New York.

Juran, J.M. and Gryna, F.M. (1993). *Quality Planning and Analysis*, 3rd edition. McGraw-Hill: New York.

Kaplan, R.S. and Norton, D.P. (1992). The balanced scorecard to work – measures that drive performance. *Harvard Business Review* **70**, 1, pp. 71-79.

Karlsson, S. (1997). *Man and Materials Flows – Towards sustainable materials management. A Sustainable Baltic Region, Session 3.* The Baltic University Programme, Uppsala University: Uppsala, Sweden.

Klemmenssen, B. (2006). *Environmental Policy – Legal and Economic Instruments*. (to be published) Baltic University Press: Uppsala, Sweden

Korbijn, A. (1999). *Vernieuwing in productontwikkeling: strategie voor de toekomst.* Stichting Toekomstbeeld der Techniek (STT): The Hague (in Dutch).

Kortman, J. R.; Van Berkel, R. and Lafleur, M. (1995). *Towards an Environmental Design Toolbox for Complex Products; Preliminary Results and Experiences for Selected Projects*. Clean Electronic Products and Technology, October 9-11, 1995.

Kotler, P. (1991). *Marketing Management: Analysis, Planning, Implementation and Control*, 12th edition. Prentice Hall: New York.

Kozlowska, B. (2004). The IPPC Directive and integrated permits – general information. In *Supplement Integrated permit in waste management,* Kozlowska, B. (ed.). Municipal Survey no. 3 (150)/2004 (in Polish).

Köllner, T. and Jungbluth, N. (1999). *Life Cycle Impact Assessement for Land Use*. Third SETAC World Congress, May 21-25, 2000, Brighton, UK.

LCANET (1996). *Board Definition Document*. The Centre of Environmental Science. Department of Industrial Ecology. Leiden University: The Netherlands. (LCANET was a project run at CML.)

Lorek, S. and Spangenberg, J.H. (2001). Indicators for environmentally sustainable household consumption. *Int. J. Sustainable Development* **4**, 1, pp. 101-120.

Marcelis, W.J. (1984). *Onderhoudsbesturing in ontwikkeling*. Kluwer: Deventer, The Netherlands (in Dutch).

Marland, G., Boden, T.A. and Andres, R.J. (2001). Global, Regional and National Fossil Fuel $CO_2$ Emissions. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, US Dept of Energy: Oak Ridge, Tenn., USA.

Max-Neef, M. (1991). *Human Scale Development*. Routledge: New York, London.

McDougall, F.; White, P.; Franke, M. and Hindle, P. (2001). *Integrated Solid Waste management: a Life Cycle Inventory,* 2nd edition. Protector & Gamble Technical Centres Limited, Blackwell Science: Oxford, UK.

McNeill, J. (2000). *Something New Under the Sun, An Environmental History of the Twentieth-Century World*. W.W. Norton: New York.

Mellor, W.; Wright, E.; Clift, R.; Azapagic, A. and Stevens, G. (2002). A mathematical model and decision support framework for material recovery, recycling and cascaded use. *European Journal of Operational Research* **102**, 2, pp. 279-294.

Miljøverndepartementet, Norwegian Ministry of the Environment (1995). Report, Oslo Ministerial Roundtable. Miljøverndepartementet: Oslo.

Mirza, R. (1998). A life cycle inventory tool for integrated waste management. A municipal focus. In *Proceedings from the International Workshop Systems Engineering Models for Waste Management, Gothenburg, Sweden.* Sundberg, J.; Nybrandt, T. and Silvertun, Å. (eds.). AFR Report 229. Swedish Environmental Protection Agency: Stockholm, Sweden.

Moll, S.; Skovgard, M. and Schepelmann, P. (2005). *Sustainable use and management of natural resources*. EEA Report 9/2005. European Topic Centre on Resource and Waste Management. EEA: Copenhagen, Denmark.

Müller-Wenk, R. (1998). *Depletion of Abiotic Resources Weighted on the Base of "Virtual" Impacts of Lower Grade Deposits in Future*. IWO Diskussionsbeitrag Nr. 57, Universität St. Gallen: Switzerland.

Månsson, B. (1993). *Miljö för bärkraftighet*. Liber Hermods: Malmö, Sweden (in Swedish).

Nielsen, A.S. (2002). *Mastering true value creation.* ICIS: Copenhagen, Denmark.

Nonaka, I. and Takeuchi, H. (1995). *The Knowledge-Creating Company*. Oxford University Press: New York.

OECD (1999). *Towards more sustainable household consumption patterns – Indicators to measure progress*. OECD: Paris.

OECD (2001). *Environmental indicators to measure decoupling of environmental pressure from economic growth ENV/EPOC (2001) 26*. OECD: Paris.

Packard, V. (1960). *The Waste Makers*. Penguin Books: Harmondsworth.

Palm, V.K. (2002). *Material Flow Accounting in Sweden.* Technical University of Denmark: Copenhagen.

Pedersen, O.G. (2002). *DMI and TMR indicators for Denmark 1981, 1990 and 1997.* An assessment of the Materials Requirement of the Danish Economy. Statistics Denmark: Copenhagen.

Pugh, S. (1991). *Total Design, Integrated Methods for successful product engineering*, Addison Wesley: Menio Park, California, USA.

Rieradevall, J. (2002). *Environmental management, new challenge for a psychology of sustainable development*. Estudos de Psicologia (Natal). Scielo (Scientific Electronic Library Online): Brazil. (http://www.scielo.org)

Russell, S. (1998). *Learning agents for uncertain environments* (extended abstract). In Proc. COLT-98. ACM Press: New York.

Rydén, E. and Strahl, J. (1995). *Proceedings of the Green Goods conference on product-based Environmental Legislation*, Kretsloppsdelegationens rapport 1995:5. Tryckfaktorn AG: Stockholm, Sweden.

Rydén, L.; Migula, P. and Andersson, A. (2003). Industrial society and chemical pollution. In *Environmental Science,* Rydén, L.; Migula, P. and Andersson, M. (eds.). Baltic University Press: Uppsala, Sweden.

Ryding, S-O. and Steen, B. (1991). *EPS–systemet. Ett PC baserat system för utveckling och tillämpning av miljöstrategiska prioriteringar i produktutvecklingen*. IVL report B1022. The Swedish Environmental Research Institute: Gothenburg, Sweden (in Swedish).

Schmidt-Bleek, F. (1994). *Wieviel Umwelt braucht der Mensch? MIPS, das Maß für ökologisches Wirtschaften*. Birkhäuser: Berlin, Basel, Boston. (English ed, Schmidt-Bleek, F. 1996. *The Fossil Makers – Factor 10 and more*. Birkhäuser, Berlin.)

Schmidt-Bleek, F. and Tischner, U. (1995). *Produktentwicklung: Nutzen gestalten – Natur schonen*. WIFI: Vienna, Austria.

Scholl, G.U. and Nisius S. (1998). *The environmental benefits to German companies through application of LCA*. Elsevier: Amsterdam.

Semeniene, D. (2003). The cost of pollution – environmental economics. In *Environmental Science*, Rydén, L.; Migula, P. and Andersson, M. (eds.). Baltic University Press: Uppsala, Sweden.

Senge, P. M. (1990). *The art and practice of learning organisation*. Doubleday/Currency: New York.

SETAC (1991) *A technical framework for LCA. Report of the workshop in Smuggles Notch, Vermont, 18-23 August, 1990*. Society of Environmental Toxicology and Chemistry, Foundation for Environmental Education: Washington DC.

SETAC (1992) *Life Cycle Assessment. Report from the SETAC workshop on LCA inventory, classification, valuation, and databases. Leiden, the Netherlands, 2-3 December 1991.* Society of Environmental Toxicology and Chemistry: Brussels.

SETAC (1993). *Guidelines for Life cycle Assessment: A "Code of Practice"*. Consoli, F.; Alleen, D.; Boustead, I.; Fava, J.; Franklin, W.; Jensen, A.A.; de Oude, N.; Parrich, R.; Perriman, R.; Postlethwaite, D.; Quay, B.; Ségui, J. and Vigon, B. (eds.). Society of Environmental Toxicology and Chemistry: Brussels.

*SimaPro Manual* (2000). Pré Consultants: Amersfoort, The Netherlands.

Spangenberg, J.H. (1994). Mensch und Müll. *Widerspruch. Münchener Zeitschrift für Philosophie* **14**, 25, pp. 51-57.

Spangenberg, J.H. (2004). The society, its products and the environmental role of consumption. In *The Ecological Economics of Consumption*, Reisch, L; Rophe, I. (eds.). E. Elgar: Cheltenham.

Spangenberg, J.H.; Femia, A.; Hinterberger, F. and Schütz, H. (1999). *Material Flow-based Indicators in Environmental Reporting*. Office for Official Publications of the European Communities: Luxembourg.

Spangenberg, J.H. and Lorek, S. (2002). Environmentally sustainable household consumption: From aggregate environmental pressures to priority fields of action. *Ecological Economics* **43**, 2-3, pp. 127-140.

Spangenberg, J.H. and Schmidt-Bleek, F. (1997) How do we probe the physical boundaries for a sustainable society? In *Foundations of a Sustainable Development – Ethics, law, culture and the physical limits. A Sustainable Baltic Region, Session 9,* Rydén, L. (ed.). Baltic University Programme, Uppsala University: Uppsala, Sweden.

Stachowicz, M. (2001). *Classification and Evaluation of Life Cycle Assessment Tools*. MS Thesis, Faculty of Process and Environmental Engineering, Technical University of Lodz: Lodz, Poland.

Stavenuiter, J. (2002). *Cost Effective Management Control of Capital Assets.* Asset Management Control Research Foundation: Medemblik, The Netherlands. (http://www.amc-rf.com)

Steen, B. (1999a). *A Systematic Approach to Environmental Priority Strategies in Product Development (EPS). Version 2000 – General systems characteristics*. CPM report 1999:4. Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology: Gothenburg.

Steen, B. (1999b). *A Systematic Approach to Environmental Priority Strategies in Product Development (EPS). Version 2000 – Models and Data of the Default Method*. CPM report 1999:5. Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology: Gothenburg Sweden.

Steen, B. and Ryding, S-O. (1992). *The EPS Enviro-Accounting Method. An application of environmental accounting principles for evaluation and valuation in product design*. IVL report B1080. The Swedish Environmental Research Institute: Gothenburg, Sweden.

Striewski, S. (2003). Optimieren des "Hin-Wegs" – Etablieren des "Rück-Wegs". In *Vision 2020. Arbeit, Umwelt, Gerechtigkeit – Strategien für ein zukunftsfähiges Deutschland*, pp. 145-164, Spangenberg, J.H. (ed.). oekom verlag: München.

Sturm, K-D. (2001). Persistente Ignoranz. *punkt.um* **2001**, 9, pp. 21-22.

Sörlin, S. and Öckerman, A. (2002). *Jorden en ö*. Natur och Kultur: Stockholm, Sweden (in Swedish).

Te Riele, H.; Zweers, A. and project group (1994). *Ecodesign: acht voorbeelden van milieugerichte produktontwikkeling*. Produktcentrum TNO/NOTA: Delft, The Netherlands (in Dutch).

The Global Footprint Network (2005). *The National Ecological Footprint and Biocapacity Accounts*. Global Assessment. (http://www.footprintnetwork.org/gfn_sub.php?content=global_footprint)

Thompson, M.; Ellis, R. and Wildavsky, A. (1990). *Cultural Theory.* Westview Print: Boulder USA.

Tischner, U. (2001). Tools for ecodesign and sustainable product design. In *Sustainable Solutions Developing Products and Services for the Future*, Charter, M. and Tischner, U. (eds.). Greenleaf-publishing: London.

Udo de Haes, H.A. and Wrisberg, N. (1997). LCANET. *European Network for Strategic Life-Cycle Assessment Research and Development*. LCA Documents, Vol 1. Eco-Informa Press. (LCANET was a project run at CML.)

UNDESA, UN Department of Economic and Social Affairs (1998). *Measuring Changes in Consumption and Production Patterns. A Set of Indicators*. United Nations: New York.

UNEP, United Nations Environment Programme (1997). *Ecodesign "A promising Approach – to sustainable production and consumption"*. Rathenau Instituut, Technical University of Delft: Delft.

UNEP, United Nations Environment Programme (2002). *Proposal for a work programme on promoting sustainable consumption and production patterns*. UNEP Documents: Nairobi.

United Nations (1993). Earth Summit: Agenda 21, the United Nations programme of action from Rio. United Nations: New York. p. 294.

Van de Meent, D.; Bakker, J. and Klepper, O. (1997). *Potentially Affected Fraction as an Indicator of Toxic Stress, Application of Aquatic and Terrestial Ecosystems in The Netherlands*. 18th Annual Meeting of SETAC, November 1997, San Francisco.

Van der Voet, E.; Kleijn, R.; Heule, R.; Ishikawa, M. and Verkijlen, E. (2002). Predicting future emissions based on characteristics of stocks. *Ecological Economics* **41**, 2, pp. 223-234.

Van Hemel, C.G. (1995). *Ecodesign empirically explored*. TUDelft: Delft, The Netherlands.

Van Hemel, C.G. (1995). The LiDS wheel. In *Ecodesign, A promising approach to sustainable production and consumption,* Brezet, H. and Van Hemel, C.G. (1997). UNEP: Paris.

Van Leeuwen, C.J. and Hermens, J.L.M. (1995). *Risk assessment of chemicals – an introduction.* Kluwer Academic Publishers: Dordrecht.

Von Weizsäcker, E.U. (1994). *Earth Politics*. Zed Books: London.

Von Weiszäcker, E.U.; Lovins, A.B. and Lovins, L.H. (1997). *The Factor Four – Doubling Wealth, Halving Resource Use.* Earthscan: London.

Wackernagel, M. and Rees, W. (1996). *Our Ecological Footprint. Reducing human impact on the Earth*. New Society Publishers: Garbiola Island, Canada.

Walker, C.; Hopkin, S.P.; Sibly, R.M. and Peakall, D.B. (2001). *Principles of Ecotoxicology*. Taylor and Francis: London.

Walz, R. (2000). Development of Environmental Indicator Systems: Experiences from Germany. *Environmental Management* **25**, 6, pp. 613-623.

WCED, World Commission on Environment and Development (1987). *Our Common Future*. Oxford University Press: Oxford.

Wenzel, H.; Hauschild, M. and Alting, L. (1997). *Environmental Assessment of Products. Volume 1: Methodology, tools, and case studies in product development*. Chapman and Hall: London, UK.

Wille, J. (2003). Ein “Saustall” soll ausgemistet werden. *Frankfurter Rundschau*, **87**, pp. 17.

Winter, G. (2002). *The Global SMALL Company Movement – Sustainable Management for All Local Leaders*. International Symposium on eco-design and green product “COMMUNICATIONS” organised by BADALONA International Business Centre. Edifici BCIN: Poligon. (http://www.bcin.org)

WSSD (2002). World Summit on Sustainable Development Plan of Implemetation. United Nations: New York.

# LCA Applications

A

The following case studies were conducted using several simplifying assumptions for practical reasons, and to make them useful as student exercises. Thus certain parts of the life cycles were omitted, proportionality was assumed where it had not been proven, and only some impact categories were studied, as detailed in each specific case.

Students working with the cases are encouraged to explore these simplifications, and perhaps avoid some of them.

# LCA 1

# Calculating MIPS for a Woman's Polo-neck Sweater

## 1 The Product and the Method

### The Company – Finn Karelia Virke Oy

Finn Karelia Virke Oy, is a Finnish company that produces women's and men's clothes of their own fabrics. The company, founded in 1945, has a turnover of 31.0 million Euros (2004) and a total personnel of 540. The company has two factories: one in Orimattila, Finland, and one in Konstantynow, Poland, and subsidiaries in Germany and in Poland. The production capacity is 6,000 pieces per day. About 90% of the production is exported to Europe, USA, Canada and Australia.

### The Product – Woman's Polo-neck Sweater

The example product is a woman's polo-neck sweater (Figure 1.1). It is produced in several different colours and sold in large numbers in Poland, Germany, Finland, Sweden and several other countries. It is made of 50/50 polyester/cotton knit. It is not self-evident what the "service unit" should consist of for a sweater. In the end the chosen unit was to wear the sweater 50 times long enough to require washing, and thus washing it after each time. The lifecycle of the sweater thus consists of production, use and 50 washings and finally the wasting of it on a landfill.

### The Method – MIPS

The MIPS method is a tool for measuring and managing the human-induced material flows. MIPS stands for Material Input Per Service unit. It is a value that can be calculated for all final products that provide a service. The MIPS value relates the natural resources consumed by a product during its entire life cycle to the overall benefit derived from it. It provides a rough – but nevertheless indicative – approximation of the product's potential environmental load. The smaller a product's MIPS value, the lower its environmental load is considered to be, because it will be consuming fewer natural resources in relation to the amount of service it produces.

Expressed as an equation, MIPS is expressed as:

MIPS = material input/service unit

The material input forming the MIPS numerator refers to the total amount of natural resources needed for the creation and use of the product in question and for its waste management. It includes not only the materials bound up within it and those required for its production, but also all the materials involved in its transportation, equipment and packaging

**Figure 1.1** *Woman´s polo-neck sweater.*

throughout its life cycle. The material input also includes the resources extracted from nature and used for producing the energy needed by the product. It thus encompasses the natural resources consumed throughout the product's entire life cycle and expresses this as a unit of mass, for example kilograms [Schmidt-Bleek, 1994].

## 2 MIPS Calculation

### Databases

The calculation of material inputs makes use of the MI factors (also called material intensities) already calculated for many widely used materials, such as steel, cement and glass, and for different means of electricity production and transportation. The MI factor expresses in kilograms, the amount of natural resources needed to create one kilogram of material or one kilowatt-hour or one ton-kilometer. In practice, material input is calculated by multiplying the material and energy consumption and transportations of the product by the corresponding MI factors.

The service unit forming the MIPS denominator refers to the benefit derived from the product. It cannot be measured like a material input but is instead determined separately for each product. The total amount of times or years of use during the life cycle are examples of what may be selected as the service unit of a product [Autio and Lettenmeier, 2002].

**Table 1.1** *Materials of the sweater.*

| Materials and components | Weight/ product (kg) | Waste/ product (kg) | Total weight (kg) | MI factor (kg/kg) | Material Input (kg) | Comments |
|---|---|---|---|---|---|---|
| Sewing thread (polyester) | 0.1155 | 0.0305 | 0.146 | 3.6 | 0.526 | Knitting room waste 1.6%<br>Selvedge waste 3%<br>Cutting waste 21.5% |
| Sewing thread (cotton) | 0.1155 | 0.0305 | 0.146 | 22 | 3.212 | Waste: see above |
| Colorant and chemicals | 0 | 0.236 | 0.236 | 1.5 | 0.354 | Salt 75%<br>Others 25% (crude oil) |
| Card labels | 0.0027 | 0.00002 | 0.0027 | 15 | 0.041 | MI factor: paper |
| Neck label | 0.0004 | | 0.0004 | 3.6 | 0.001 | |
| Product label | 0.0003 | | 0.0003 | 3.6 | 0.001 | MI factor: polyester |
| Cutting plastic | | 0.0009 | 0.0009 | 5.4 | 0.005 | |
| Cutting paper | | 0.0026 | 0.0026 | 15 | 0.039 | |
| Lot label | | 0.0004 | 0.0004 | 15 | 0.007 | |
| Water | | | | | | 50.28 l/sweater, from own wool |
| | | | | **Total:** | **4.18** | |

**Table 1.2** *Packing materials of the sweater.*

| Materials and components | Weight/ product (kg) | Waste/ product (kg) | Total weight (kg) | MI factor (kg/kg) | Material Input (kg) | Comments |
|---|---|---|---|---|---|---|
| Bobbin | | 0.005 | 0.005 | 3 | 0.014 | Measured, divided per sweater by weight |
| Wooden platform | | 0.016 | 0.016 | 2.2 | 0.035 | See above |
| Cardboard | | 0.014 | 0.014 | 3 | 0.041 | See above |
| Plastic bag | 0.003 | | 0.003 | 5.4 | 0.016 | See above |
| Hangers | 0.038 | | 0.038 | 7 | 0.266 | Measured |
| | | | | **Total:** | **0.37** | |

**Table 1.3** *Electricity consumption in the production of the sweater.*

| Electricity (public network) | Electric Energy Input (kWh) | MI factor (kg/kWh) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Knitting | 0.2 | 0.41 | 0.082 | Partial estimate |
| Dyeing and finishing | 0.28 | 0.41 | 0.115 | Partial estimate, partly based on the machine wattage |
| Cutting and sewing | 0.01 | 0.41 | 0.004 | Based on the wattage of the cutter |
| | | **Total:** | **0.20** | |

**Table 1.4** *Other energy consumption in the production of the sweater.*

| Source of energy (oil, natural gas etc.) | Weight (kg) | MI factor (kg/kg) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Natural gas | 0.354 | 1.3 | 0.46 | Partial estimate |
| | | **Total:** | **0.46** | |

## Production Phase

The MIPS calculation of the sweater is shown below step by step. The calculations concerning the production phase has been published in Finnish in Autio and Lettenmeier [2002].

Calculation of the material input of the production phase starts with listing all the materials of the sweater (Table 1.1). The weight of each material and the amount of waste that is produced in the production processes are expressed in kilograms and added up. Then, the total weight of each material is multiplied with a corresponding MI factor. The result is the material input in kilograms. Comments concerning the calculation are written in the comments column.

Also the packing materials of the sweater and all the packing material waste created in the production phase are listed and expressed in kilograms (Table 1.2). The total weight of each packing material is multiplied with a corresponding MI factor.

The electricity consumption of production is expressed in kilowatt-hours (Table 1.3) and other sources of energy in kilograms (Table 1.4). Again, the material inputs are calculated by using the MI factors.

Also the transportation distances from the suppliers to the company and from the company to the customers need to be determined. The distances (expressed in kilometres) are mul-

### The Finnkarelia Company

**Factories**

Finnkarelia was founded in 1945 and has two factories.

The Orimattila factory in Finland was completed in 1970 and has since then been expanded eight times. The factory floor area is more than 5,2 acres (22,000 m²).

Production in the Konstantynow factory, Poland, started in autumn 1991.

**Production**

Production starts with the yarn, which is knitted in the knitting department at a capacity of 2,000 to 2,300 kg a day. The modern and environmentally friendly machinery guarantees a fast finishing of the cloth and also an efficient development of the product.

Computerised production planning coupled with a high level of garment manufacturing technology enables the factory to process the fabrics through the cutting department, where automatic computer driven cutters cut 10 km of cloth daily.

The cut pieces are transferred to the sewing departments in Orimattila and Poland. In the finishing department the garments get their final touch. An automatic transport system then transfers the garments to the warehouse with a capacity of 300,000 pieces. From the warehouse the garments are then delivered to the customers.

*http://www.finnkarelia.com*

**Table 1.5** *Transports in the production of the sweater.*

| Mode of transportation | Distance (km) | Weight of transported goods (t) | Distance x weight (tkm) | MI factor (kg/tkm) | Material Input (kg) | Comments |
|---|---|---|---|---|---|---|
| Truck, incoming | 1523 | 0.000291 | 0.443 | 1 | 0.443 | Sewing thread + colorant |
| Ship, incoming | 1134 | 0.000291 | 0.330 | 0.006 | 0.002 | |
| Truck, outbound | 1523 | 0.000234 | 0.356 | 1 | 0.356 | Sweater |
| Ship, outbound | 1134 | 0.000234 | 0.265 | 0.006 | 0.002 | |
| | | | | **Total:** | **0.80** | |

tiplied with the mass of transported goods (expressed in tons). The ton-kilometers are then multiplied with the MI factors. Different modes of transport are dealt with separately.

## Use Phase

In this calculation, the use phase includes the washing of the sweater. Both the production of the washing machine and the electricity consumption during the use of the machine are included. In Table 1.6 the material input of the materials of the washing machine is calculated in the same way as above for the sweater. Also the material input caused by transportations (Table 1.7) and the electricity consumption in the production phase of the washing machine (Table 1.8) are calculated.

Since there are also other clothes to be washed in the washing machine, the material input of the machine must be allocated per one sweater. The total material input of the washing machine is 1588 kg + 35.42 kg + 22.55 kg = 1645.97 kg. It is presumed that the washing machine can wash 2,000 times during its life cycle. This means that one wash consumes 1645.97 kg / 2000 = 0.823 kg natural resources. Presumed that there are ten sweaters at the same time in the washing machine and that one sweater will be washed 50 times during its life cycle, the following amount of the material flows of the washing machine can be allocated for one sweater: (0.823 kg / 10) x 50 = 4.115 kg.

Also the electricity consumption during the use of the washing machine must be taken into account (Table 1.9). If a sweater is washed 50 times in +40ºC during its life cycle, 9.81 kWh of electricity is consumed. This corresponds to 4.02 kg of natural resources.

**Table 1.6** *Materials of a washing machine.*

| Material | Weight/ product (kg) | MI factor (kg/kg) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Steel | 24.5 | 7 | 171.5 | |
| Copper | 1.33 | 500 | 665 | |
| Tin | 0.07 | 6800 | 476 | |
| Aluminium | 1.4 | 85 | 119 | |
| Iron | 7 | 5.6 | 39.2 | |
| Zinc | 0.7 | 23 | 16.1 | |
| Glas | 1.4 | 3 | 4.2 | |
| Cement | 20.3 | 1.3 | 26.39 | |
| Plasic | 11.2 | 5.4 | 60.48 | MI factor: polyethylene |
| Rubber | 2.1 | 5 | 10.5 | |
| | | **Total:** | **1588** | |

**Table 1.7** *Transports of a washing machine.*

| Mode of transportation | Distance (km) | Weight of transported goods (t) | Distance x weight (tkm) | MI factor (kg/tkm) | Material Input (kg) | Comments |
|---|---|---|---|---|---|---|
| Truck transport | 500 | 0.070 | 35 | 1 | 35 | |
| Sea transport | 1000 | 0.070 | 70 | 0.006 | 0.42 | |
| | | | | **Total:** | **35.42** | |

| Electricity (public network) | Electric Energy Input (kWh) | MI factor (kg/kWh) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Electricity | 55 | 0.41 | 22.55 | |
| | | **Total:** | **22.55** | |

**Table 1.8** *Electricity consumption in the production of a washing machine.*

| Electricity (public network) | Electric Energy Input (kWh) | MI factor (kg/kWh) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Electricity | 9.81 | 0.41 | 4.02 | |
| | | **Total:** | **4.02** | |

**Table 1.9** *Electricity consumption caused by the washing of the sweater (in +40ºC, 50 times).*

| Waste disposal | Weight/ product (kg) | MI factor (kg/kg) | Material Input (kg) | Comments |
|---|---|---|---|---|
| Landfill deposit | 0.231 | 1.1 | 0.25 | |
| | | **Total:** | **0.25** | |

**Table 1.10** *Waste disposal of the sweater.*

**Table 1.11** *Life-cycle-wide material flows of the sweater.*

| Production | Material Input (kg)/sweater | % |
|---|---|---|
| Materials | 4.18 | 29.0 |
| Packing materials | 0.37 | 2.6 |
| Electricity consumption | 0.20 | 1.4 |
| Other energy consumption | 0.46 | 3.2 |
| Transports | 0.8 | 5.6 |
| *Subtotal* | *6.01* | *41.7* |
| **Usage** | **Material Input (kg)/sweater** | **%** |
| Washing machine | 4.12 | 28.6 |
| Electricity consumption of the washing machine | 4.02 | 27.9 |
| *Subtotal* | *8.14* | *56.5* |
| **Waste disposal** | **Material Input (kg)/sweater** | **%** |
| Landfill deposit | 0.25 | 1.8 |
| *Subtotal* | *0.25* | *1.8* |
| **Total** | **14.40** | **100** |

### Waste Disposal Phase

It is assumed that the sweater will end up on a landfill in the end of its life cycle. The material input of the landfill treatment is calculated in Table 1.10.

## 3 Overall Results of the Calculation

### Summation of the Material Inputs

The life-cycle-wide material inputs of the sweater are summed up in Table 1.11. About 57% of the natural resource consumption originates from the use of the sweater. About 42% of the natural resource consumption is caused by the production phase, in which the materials of the sweater are the most important factor. Waste disposal causes only 2% of the natural resource consumption of the sweater.

It must be emphasized that the MI factor used for electricity consumption in this calculation represents average power production in Finland. The MI factor for power production varies very much between different countries. For example, the MI factor for power production in Germany is about ten times bigger than the Finnish one. Thus, it has a significant impact on the results, which MI factors are being used.

### Service Unit (S) and the MIPS Value

In order to calculate a MIPS value for the product, also the service unit must be defined. In the case of a sweater, the service unit could be defined for example as the amount of times the sweater is worn or the amount of times the sweater is washed during its life cycle. In this calculation, the latter is chosen. As mentioned it is assumed that the sweater will be washed 50 times during its life cycle. Therefore, the MIPS value of the sweater is:

MIPS = MI/S = 14.40 kg/50 washes = 0.288 kg/washing cycle ≈ 0.3 kg/washing cycle

## 4 Reducing MIPS, Increasing Material Efficiency

### Ways to Reduce Material Intensity

In order to increase material efficiency of the product, the MIPS value needs to be reduced. This can be achieved either by diminishing the material input of the product or by increasing the amount of service the product produces during its life cycle. The material input of the product can be diminished, for example, by changing the materials of the product, by decreasing the amount of waste created in the production phase, by optimising packaging, by decreasing the use of energy and by minimizing the transportations. The service of the product can be increased, for example, by prolonging the service life of the product and by making the product versatile.

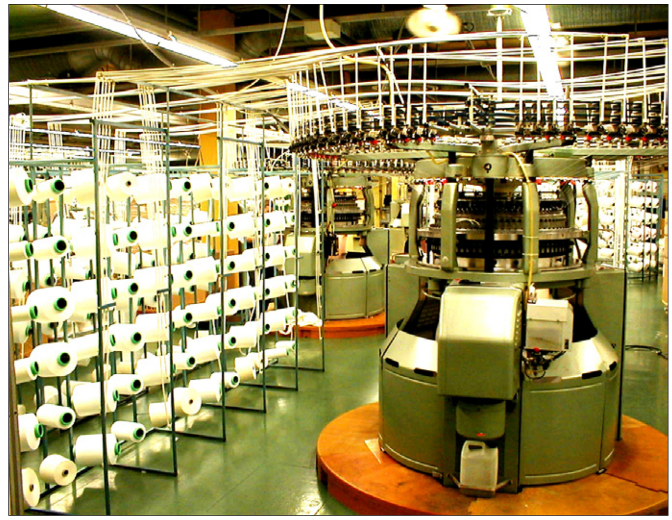


**Figure 1.2** *Production starts with the yarn, which is knitted in the knitting department at a capacity of 2,000 to 2,300 kg a day.*

For example, if the cotton in the sweater was replaced with viscose, the life-cycle-wide material input of the sweater would decrease from 14.4 kg to 11.9 kg per sweater. If the sweater were made purely out of cotton, its material input would be ca. 16.8 kg per sweater. Thus, the strategy of using mixed textiles chosen by Finn Karelia Virke Oy can be considered resource efficient.

Also the consumer can affect the MIPS value of the sweater. Ten sweaters at the same time in the washing machine, as assumed in the calculation, is perhaps not that much. Washing laundry only in full washing machines is a way to decrease the MIPS value of clothes.

It is also important to take proper care of the sweater and to avoid unnecessary washing of the garment. This way it is possible to prolong the service life of the sweater and to reduce the electricity consumption during the use phase.

As Finnish electricity has a relatively small material intensity, the relevance of the washing as a part of the life cycle of the sweater may even radically increase outside Finland. Thus, the strategy chosen by Finn Karelia Virke Oy of producing textiles that can be washed at low temperatures can be considered resource efficient, too. Drying the sweater in a tumble dryer would also increase the material input over the life cycle.

As shown in this example, the MIPS-concept enables companies to make life cycle considerations based on relatively simple calculations. From a life cycle point of view, the production process within the company is not the only relevant phase. Thus, a company should also think about its options to reduce the material input on the consumer side. Finn Karelia

#### Student Exercise

A students' exercise would be to repeat the calculation of the MIPS for the sweater. Vary the study by letting different student groups examine the consequences of the following changes:

1. Calculate the MIPS including all five resource categories available today.
2. Vary the assumption on how many sweaters can be part of a single wash. Check several different washing machines. They use quite different amounts of electricity per kg of clothing and different washing programs.
3. Vary some other assumptions, for example a) that the wasted sweater is sent to solid waste incineration, which would be the most typical today b) that the electricity would be taken in Poland and Germany instead of Finland c) that the transport of the resources to the plant is different.

After the study estimate which factor is the most important for reducing the MIPS. Make an assessment specifically of the greenhouse gas emission for the various assumptions.

Virke, for instance, has spent some efforts on communicating the advantages of low washing temperatures to the consumers. Also the production of textiles less disposed to quick changes in fashion has been a way to ensure the resource efficiency of the products produced by the company.

### Improving the Calculation

The MIPS calculation presented here was calculated already in 2001. The MI factors used in the calculation have since been improved. Thus in this calculation only the solid natural resources – the sum of abiotic and biotic resources – are included in the calculation. Since some time the natural resources are divided into five different categories in the MIPS calculation: abiotic natural resources, biotic natural resources, water, air and what is termed "earth movement in agriculture and forestry". Five different MIPS values can thus be calculated for any product. [Ritthoff et al., 2002] Updated MI factors for all five natural resource categories can be found at the Wuppertal Institute's web page.

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## References

Autio, S. and Lettenmeier, M. (2002). Ekotehokkuus – Business As Future. Yrityksen ekoteho-opas *(Eco-efficiency – business as future. A corporate guide to eco-efficiency)*. Dipoli reports C, environmental training. Espoo: Helsinki University of Technology Lifelong Learning Institute Dipoli. 80 p. (In Finnish)

Ritthoff, M., Rohn, H. and Liedtke, C. (2002). Calculating MIPS. Material productivity of products and services. *Wuppertal Spezial 27e.* Wuppertal: Wuppertal Institute for Climate, Environment and Energy at the Science Centre North Rhine-Westphalia. 52 p. *http://www.wupperinst.org/Publikationen/Wuppertal_Spezial/ws27e.pdf* (Also in German, Russian and Finnish.)

Schmidt-Bleek, F. (1994). *Wieviel Umwelt braucht der Mensch? MIPS, das Maß für ökologisches Wirtschaften*. Birkhäuser: Berlin, Basel, Boston. (English ed, Schmidt-Bleek, F. 1996. *The Fossil Makers – Factor 10 and more*. Birkhäuser, Berlin.) *http://www.factor10-institute.org/seitenges/Pdf-Files.htm*

## Internet Resources

### Wuppertal Institute – Material Intensity factors of materials and energy sources

*http://www.wupperinst.org/Projekte/mipsonline/download/MIT_v2.pdf*

# CA 2 A Comparative LCA Analysis of a Passenger Car and a Municipal Bus using Different Simplified LCA Methods

## 1 Background

### Several Different Methods

A comparative Life Cycle Assessment of a car, as an example of individual transport, and a bus, as an example of mass transport, is made in this case, adapted from a student project. In the assessment we will use several methods, most of them resulting in single indices. These indices are based on material flows in kg (the MIPS method), emissions (Eco-points), or money (EPS 2000), etc. Together the methods point to different aspects of the environmental impacts of the two means of transport and give a fairly good understanding of how the two compare.

The case illustrates the possibility to make approximate comparisons using the simplified methods, in contrast to a full scale LCA, which requires much larger investments in both data collection and modelling. There are also several examples on how to estimate data rather than go very far in trying to collect more precise data. As all transport depends on a large and complex system of access to fuel, repair, road infrastructure etc. the case finally illustrates the difficulties to set system boundaries and define the functional units.

### Basic Data for the Car and the Bus

The data for the car in this analysis were provided by the Wuppertal Institute based on an LCA analysis of a specific passenger car from a car company in Germany (Wuppertal Institute, 1998). An inventory analysis of material and energy flows for the entire life cycle of a municipal bus was carried out in the Motorcar Factory Jelcz S.A. (the production phase) and at the Municipal Bus Company in Lodz, Poland (Szubka, 1999]) (use phase).

In the analysis, the life span of the car was assumed to be 10 years, while that of a bus to be 12 years. Additionally, it was assumed that during its life the car is driven 130,000 km (13,000 km/year), while the bus was driven 960,000 km (80,000 km/year).

All data necessary for a proper calculation of the total impact on the environment by transport (both individual and mass transport) during its entire life cycle could not be found. Thus some indices for the two types of transport were assumed to be identical, and some data were estimated, as will be specified below.

Obviously the data for both the bus and the car could be dramatically different for a different car and a different bus. We assume that the data used are fairly representative, keeping in mind that some buses and cars are much better, and probably some much worse, when it comes to environmental impacts.

## 2 A MIPS (Material Intensity Per Service Unit) Analysis

### The MIPS Analysis

In the MIPS method the material flows expressed in kg associated with a specific service, in this case a transport service, is estimated. Data were collected for all material flows caused by the car and the bus over their life cycles. The impacts were then related to the number of passenger kilometres, which the two means of transport had provided during their lifetimes.

Data were collected for the production of the car and the bus, and their use. The wasting of the bus and the car after the end of their lives was not treated. The use phase dominated the analysis totally.

## Material Intensity During Production

Data of materials and energy used during the whole passenger car life cycle was downloaded from the Wuppertal Institute *(http://www.wupperinst.org/Projekte/mipsonline/index.html)*. The data was based on an LCA analysis for one car company in Germany [Wuppertal Institute, 1998]. Data for production of the car are cited in Table 2.1.

Lacking exact data concerning the bus, the amount of materials used in the production of a municipal bus was estimated by comparison with the car. The material use in the production of the bus was assumed to be proportional to the use in the car. As the weight of the car was 1,071 kg, and that of the bus, i.e. 10,000 kg; the proportion is 10,000/1,071=9.3. The amount of electric energy use in the production was estimated to be 8 times higher for the bus as compared to the car (Table 2.1).

## Material Intensity for Use

The analysis of material intensity of the use phase of the vehicles themselves requires information on

- Fuel consumption.
- Tires used.
- Materials for maintenance (repair and service).
- Water for washing.

The analysis of material intensity of the transport infrastructure requires information on

- Materials for building and maintaining the roads.
- Materials for peripheral infrastructure (street lights and parking lots).

Data for both means of transport for the stage of operation collected during the inventory analysis are shown in Table 2.2. Material intensity data for the use phase for the car was received from the Wuppertal Institute. Data for the bus was collected at the Municipal Bus Company in Lodz.

In the case of Lodz municipal buses, fuel consumption is 34.3 l per 100 km; at a density of 0.830 kg/l we obtain the value of 28.5 kg fuel used per 100 km. A bus drives 80,000 km per year, using 22,775 kg fuel annually (in a 12-year life cycle this value reaches 273,302 kg). According to our information, oil consumption constitutes 1% in relation to the fuel consumption, hence per 100 km it is 0.343 l (oil density = 0.900 kg/l) and 0.309 kg, respectively. The annual oil consumption is 246.4 kg per 80,000 km, and in the whole life cycle it is 2,957 kg.

The amount of spare parts used during a major repair of the bus is 1,603 kg. Such a repair is made four times a year, so annually this makes 6,415 kg, and during the whole life cycle 76,979 kg.

As for the energy used for vehicle heating, the bus was heated for 198 hours (50 h in November, 77 h in December, 22 h in January and 49 h in February (data for the year 1998/99). The fuel consumption standard for heating is 3.5 l/h. The total amount of fuel used for heating is thus 693 l or 575 kg. For the whole life cycle this amounts to 6,902 kg. The figure is obviously only approximate since the heating depends on outdoor temperature.

Tires in a bus are changed every third year (6 tires, each weighing 58 kg). So, during the whole life cycle it makes 1,392 kg.

In Poland, municipal buses are washed every day, except in winter, when the ambient temperature is below -3°C. Then they are washed every third day. This adds up to a total of 280 days a year on average. During 12 years the bus is therefore washed 3360 times.

## Waste Management During the Use Phase

The transport intensity of the waste produced during the use of the car or bus, the unit tkm, defined as t tons transported k kilometres is used (Table 2.3).

Copper, brass, aluminium, lead and steel scrap coming from repairs and disassembly of road devices and equipment as well as the bus amounts to 1,328 kg. The material is sold to companies located at a distance of 30 km. The transport of scrap metal this distance thus adds up to 39.8 tkm annually, i.e. 478 tkm during the whole life cycle of the bus.

The 60 kg car batteries of the bus are changed every 3 years. The batteries are then disposed of at the Mining and Steel Works "Orzel Bialy" in Bytom at a distance of about 190 km. Since 4 sets of batteries are used during the life cycle of the bus this adds up to annually 60x190/4=2.9 tkm, and for the whole life cycle 34.8 tkm.

Rubber waste (tires, small plastic parts, elements of devices) in the amount of 501 kg are utilized in the Cement Plant Górazdze (distance from Lodz is about 190 km, there are also 4 changes in the life cycle, hence 501x190/4=23.8 tkm per year and 286 tkm in the entire life cycle).

Other fractions of plastics coming from disassembly and repairs, moulded pieces of seats reinforced with glass fibres, information boards, plastic parts of bus interior equipment, in the amount of 150 kg are disposed at the landfill of Chemical Plants "Boruta". The distance is about 12 km from Lodz; it adds up to 1.8 tkm in the whole life cycle.

On the whole, every year waste is transported at a distance of 422 km, so it is easy to calculate the quantity of fuel used in the entire life cycle as 1443 kg. The amount of energy used was also estimated.

## End-of-life

The final scrapping of the car and the bus is not included in the analysis. However it is clear that if the total weight of the bus is 10,000 kg and a total of 76,979 kg are used in the maintenance during its life cycle, the material flows due to scrapping amounts to 12% of the waste management of the use phase. It is thus not qualitatively important, and can be neglected for the purpose of this project.

## The LCA Analysis According to the MIPS Method

The MIPS was calculated for a total distance of car driving of 130,000 km, and for the bus 960,000 km during the life cycles of the two vehicles (car 10 years and bus 12 years). The material intensity was also calculated per person and distance, that is, transport service, using the unit "transporting a person 1000 km". It was then assumed that the car carries 4 passengers, while the bus takes 100 passengers. Note, that changing the assumption so that the car carries on average 2 passengers and the bus 50, will not change the comparison. The results of the calculations are given in Tables 2.4 and 2.5.

## Conclusions

The life cycle assessment was made on the basis of material intensity indices (MI). The material intensity depends on the size of the so-called ecological rucksack of the material. Thus for producing 1 kg of virgin (not recycled) copper 500 kg of other materials have to be moved. The ecological rucksack is about 500 kg and the Material Intensity of copper is 500. The material Intensities are expressed for both solid (abiotic) material, water and air. Thus to produce 1 kg of virgin copper, 500 kg of solid material, 260 l (or kg) of water, and 2 kg of gaseous material are moved (cf. second row in Table 2.4).

Tables 2.4 and 2.5 show the total material flows of the car and the bus during their life cycles. They are estimated as the sum of impacts during. production, exploitation/usage and for the accompanying waste management. The materials intensity of the bus is much higher than that of the car. The ratio between the two is 37 times (from the ratio of the sum of the total loads =18020653/489881).

However, taking into account that the bus during its entire life cycle covers a distance 7.4 times longer and carries 25 times more passengers than a car, the impact produced by a municipal bus related to one kilometre and one passenger is about 5.0 times smaller then a passenger car (ratio of the sum of total loads/1000 km/ passenger =942/188).

So, let us use a bus for transportation in the city and leave our car in a garage!

**Table 2.1** *Material and energy used for production of a car and a bus.*

| Production: materials/ products/modules | Car | Bus |
|---|---|---|
| Steel | 710 kg | 6630 kg |
| Copper | 10 kg | 93 kg |
| Aluminium | 70 kg | 654 kg |
| Plastics | 31 kg | 289 kg |
| Glass | 35 kg | 327 kg |
| Working liquids | 120 kg | 1120 kg |
| Non-electric energy | 95 kWh | 890 kWh |
| Electric energy | 650 kWh | 5200 kWh |
| Catalytic converters | 1 unit | 2 units |

**Table 2.2** *Materials and energy used during the use phase.*

| Operation: materials/ products/modules | Car | Bus |
|---|---|---|
| Fuel | 8,242 kg | 273,30 kg |
| Oil | 53 kg | 2,957 kg |
| Tires | 56 kg | 1,392 kg |
| Maintenance (energy, spare parts) | 60 kg | 83,881 kg |
| Road infrastructure | 130 kg | 300 kg |
| Peripheral infrastructure | 130 kg | 300 kg |
| Car washing | 46 units | 3360 units |

**Table 2.3** *The amount of materials and energy used during waste management.*

| Waste management: materials/products/ modules | Car | Bus |
|---|---|---|
| Non-electric energy | 5 kg | 46.6 kg |
| Fuel | 3 kg | 1443 kg |
| Electric energy | 22 kWh | 205 kWh |
| *Transport* | | |
| User-reuser | 21.4 tkm | 286 tkm |
| Disassembly-scrapping | 80.4 tkm | 478 tkm |
| Scrapping-disposal site | 2.09 tkm | 36.6 tkm |

**Table 2.4** *Results of life cycle assessment of a car on the basis of material intensity (MI) index.*

| Material/product Vehicle: CAR | Amount | MI | Abiotic material (kg) | MI | Water (kg) | MI | Air (kg) |
|---|---|---|---|---|---|---|---|
| Production stage | | | | | | | |
| Steel | 710 kg | 7.0 | 4970 | 44.2 | 31,666 | 1.3 | 923 |
| Copper | 10 kg | 500 | 5000 | 260 | 2,600 | 2.0 | 20.0 |
| Aluminium | 70 kg | 85.0 | 5950 | 1379 | 96,530 | 10.0 | 700 |
| Plastics | 31 kg | 8.0 | 248 | 117.7 | 3648.7 | 0.7 | 21.7 |
| Glass | 35 kg | 3.0 | 105 | 11.7 | 409.5 | 0.7 | 24.5 |
| Operating liquid | 120 kg | 1.2 | 144 | 4.3 | 516 | 3.1 | 372 |
| Non-electric energy | 95 kg | 1.4 | 133 | 9.5 | 902.5 | 3.1 | 294.5 |
| Catalytic converter | 1 element | 2000 | 2000 | - | - | - | - |
| Process energy | 650 kWh | 4.7 | 3055 | 83.1 | 54,015 | 0.6 | 390 |
| *Subtotal* | | | *21,605* | | *190,288* | | *2,746* |
| Use phase | | | | | | | |
| Fuel | 8242 kg | 2.5 | 20,605 | 11.7 | 96,431.4 | 3.3 | 27,199 |
| Oil | 53 kg | 1.2 | 63.6 | 4.3 | 227.9 | 3.1 | 164.3 |
| Tires | 56 kg | 2.9 | 162.4 | 19.4 | 1086.4 | 0.7 | 39.2 |
| Maintenance | 60 kg | 12.5 | 751.2 | 92.5 | 5550 | 1.6 | 96.0 |
| Road infrastructure | 130 kg | 150 | 19,500 | 211.7 | 27,521 | 5.1 | 663 |
| Peripheral infrastructure | 130 kg | 21.2 | 2,756 | 319.6 | 41,548 | 2.4 | 312 |
| Washing | 46 units | 27.5 | 1265 | 583.7 | 26,850 | 3.5 | 161 |
| *Subtotal* | | | *42,103* | | *199,215* | | *28,634* |
| Waste management during use | | | | | | | |
| Fuel | 3 kg | 2.5 | 7.5 | 11.7 | 35.1 | 3.3 | 9.9 |
| Non-electric energy | 5 kg | 1.4 | 7.0 | 9.5 | 47.5 | 3.1 | 15.5 |
| Electric energy | 22 kwh | 4.7 | 103.4 | 83.1 | 1828 | 0.6 | 13.2 |
| Total transport | 103.9 tkm | 0.25 | 26 | 1.8 | 187.0 | 0.1 | 10.4 |
| *Subtotal* | | | *144* | | *2,098* | | *49.0* |
| Total load | | | 66,852 | | 391,600 | | 31,429 |
| Total load/1000 km | | | 514 | | 3012 | | 242 |
| Total load/1000 dkm/passenger | | | 129 | | 753 | | 60 |

**Table 2.5** *Results of life cycle assessment of a bus on the basis of material intensity (MI) index.*

| Material/product<br>Vehicle: BUS | Amount | MI | Abiotic material (kg) | MI | Water (kg) | MI | Air (kg) |
|---|---|---|---|---|---|---|---|
| Production stage | | | | | | | |
| Steel | 6630 kg | 7.0 | 46,410 | 44.6 | 295,698 | 1.3 | 8619 |
| Copper | 93 kg | 500.0 | 46,500 | 260 | 24,180 | 2.0 | 186 |
| Aluminium | 654 kg | 85.0 | 55,590 | 1379 | 901,866 | 10.0 | 6540 |
| Plastics | 289 kg | 8.0 | 2,312 | 117.7 | 34,015 | 0.7 | 202.3 |
| Glass | 327 kg | 3.0 | 981 | 11.7 | 3,826 | 0.7 | 228.9 |
| Operating liquid | 1120 kg | 1.2 | 1,344 | 4.3 | 4,816 | 3.1 | 3472 |
| Non-electric energy | 890 kg | 1.4 | 1,246 | 9.5 | 8,455 | 3.1 | 2759 |
| Catalytic converters | 2 elements | 2000 | 4,000 | - | - | - | - |
| Process energy | 5200 kWh | 4.7 | 24,440 | 83.1 | 432,120 | 0.6 | 3120 |
| *Subtotal* | | | *182,823* | | *1704,976* | | *25,127* |
| Use phase | | | | | | | |
| Fuel | 273300 kg | 2.5 | 683,250 | 11.7 | 3197,610 | 3.3 | 901,890 |
| Oil | 2957 kg | 1.2 | 3,548 | 4.3 | 12,715 | 3.1 | 9166.7 |
| Tires | 1392 kg | 2.9 | 4,037 | 19.4 | 27,005 | 0.7 | 974.4 |
| Maintenance | 83,881 kg | 12.5 | 1050,190 | 92.5 | 7758,993 | 1.6 | 134,210 |
| Road infrastructure | 300 kg | 150 | 45,000 | 211.7 | 63,510 | 5.1 | 1530 |
| Peripheral infrastructure | 300 kg | 21.2 | 6360 | 319.6 | 95,880 | 2.4 | 720 |
| Washing | 3360 units | 27.5 | 92,400 | 583.7 | 1,961,232 | 3.5 | 11,760 |
| *Subtotal* | | | *1884,785* | | *13,116,944* | | *1060,251* |
| Waste management during use | | | | | | | |
| Fuel | 1443 kg | 2.5 | 3608 | 11.7 | 16,883 | 3.3 | 4762 |
| Non-electric energy | 46.6 kg | 1.4 | 65.2 | 9.5 | 442.7 | 3.1 | 144.5 |
| Electric energy | 205 kWh | 4.7 | 963.5 | 83.1 | 17,035.5 | 0.6 | 123 |
| Total transport | 799.6 tkm | 0.25 | 199.9 | 1.8 | 1439 | 0.1 | 80 |
| *Subtotal* | | | *4836* | | *35,801* | | *5,109* |
| Total load | | | 2072,444 | | 14,857,721 | | 1090,487 |
| Total load/1000 km | | | 2159 | | 15477 | | 1136 |
| Total load/1000 dkm/passenger | | | 22 | | 155 | | 11 |

> **Student Exercise**
>
> All steps in the "Means of Municipal Transport" project described in the book can be analysed during classes with students using appropriate software. The calculations described here were made with the SimaPro Demo version.

## 3 LCA Analysis According to Eco-indicator and Eco-point Methods

### Introduction

To check the reproducibility of different techniques used for Life Cycle Assessment the same analysis was carried out using other impact assessment techniques (Eco-indicator 95 and 99, Eco-points, EPS 2000, etc).

The MIPS analysis showed that the car had 37 times less impact than the municipal bus if the total environmental loads were considered, but that the bus had 5.0 times less environmental impact than the car per passenger kilometre. The quantitative results of the MIPS analysis are difficult to compare to any other LCA techniques as they are measuring other parameters. However, the ratio of the impacts should be similar despite of which assessment technique is used.

That is why the main aim of this case study is to determine similar relationships from other impact assessment techniques. The analyses presented below was carried out on the basis of SimaPro software and database.

In the same way as in the MIPS analysis, the life cycle of a car was determined to be 10 years, while that of a bus to be 12 years. Additionally, it was assumed that during its life cycle a car drives 130,000 km (13,000 km/year), while a bus drives 960,000 km (80,000 km/year).

### Functional Unit

The functional unit was chosen on the basis of the number of kilometres covered in one year by each vehicle taking the number of passengers into consideration.

During its 12-year's life cycle a bus travels a total of 960,000 km carrying on average 100 passengers. It gives: 960,000 km x 100 passengers/12 years = $8 \times 10^6$ passenger kilometres/year. For a car accordingly: 130000 km x 4 passengers/10 years = $0.052 \times 10^6$ passenger kilometres/year. As a point of reference, one bus must be compared to 154 cars ($8 \times 10^6 / 0.052 \times 10^6$).

### Data Collection

Since the analysis is supposed to check the reproducibility of different techniques, all the data has been derived from the

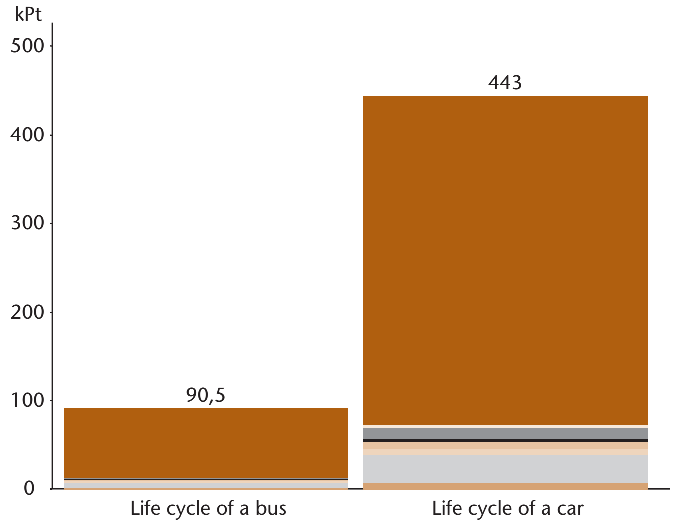


**Figure 2.1** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle "life cycle of a bus" with 154 p life cycle "life cycle of a car". Method used: Eco-indicator 99 (H) / Europe Ei 99 H/H/ single score.*



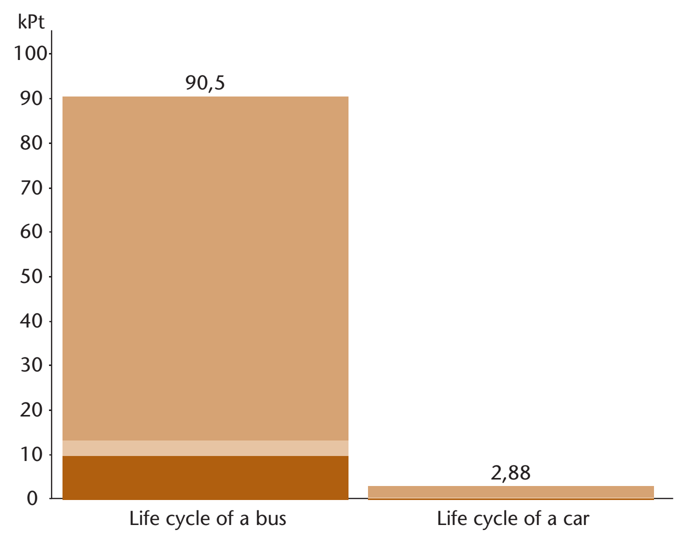


**Figure 2.2** *Environmental indices for LCA analysis of a passenger car and municipal bus regardless of the functional unit. Comparing 1 p life cycle 'life cycle of a bus' with 1 p life cycle 'life cycle of a car'. Method used: Eco-indicator 99 (H) / Europe Ei 99 H/H/ single score.*

MIPS analysis without any changes if possible. However, due to different methodologies or the lack of the appropriate data, applied models of life cycles have to be modified to some extent. The following assumptions were introduced into the analysis:

- "Plastics" (in MIPS) was assumed to be PVC (in Eco-indicator).
- "Operating liquids" and "oil" were assumed to be diesel oil mechanical energy i.e. diesel engine under continuous changing load was used as "non-electric energy" (MIPS).
- 10 g of platinum was assumed as an equivalent of one "catalytic converter".
- Unleaded petrol was used as "fuel" (MIPS) (fuel for heating was added for the bus).
- Steel for spare parts was used as "maintenance".
- "Road and peripheral infrastructure" was modelled by taking the appropriate data straight from the SimaPro database.
- Due to the lack of data, washing of the vehicles has been omitted.
- Waste management has been described by a disposal scenario in which all the metals are recycled, plastics are land filled and tyres incinerated.

## Eco-indicator 99

The Eco-indicator 99 gives the environmental impact as data for 11 parameters to reflect resource use, human health and eco-systems quality (Figure 2.1). These are added up to a single score.

Figure 2.1 shows the results of an LCA analysis for the passenger car and the municipal bus as single scores, environmental indices, from Eco-indicator 99. In the analysis, in the weighting phase, the highest significance was given ecosystem quality.

Figure 2.1 shows that Eco-indicator 99 gives similar results as those obtained from the MIPS analysis. Environmental impact generated by a car and municipal bus per 1 passenger and 1 kilometre are equal to 443 and 90.5 units respectively. The ratio of single scores in the Eco-indicator 99 method is then 4.9 (443/90.5) which matches perfectly the result from MIPS analysis (5.0). As it is shown in the graph, in both cases, the main environmental burden is caused by fuel consumption in the use phase. Crude oil consumption constitutes over 80% of the single score. Emissions of sulphur and nitric oxides are also noteworthy (3-4%). Similar data are seen in the MIPS analysis.

It was also found that, irrespective of the weighting factors, the life cycle of the bus had the better environmental profile.

The total environmental impacts of the life cycles of the car and the bus, without restricting them to a functional unit, were also determined.

Figure 2.2 shows the results for comparing one life cycle of the bus to one life cycle of the car. The estimations are that the life cycles the bus has over thirty times (1:31.5) higher environmental index than a car (90.5/2.88). This is due to higher fuel, material and energy consumption in both production and operational stages. In the MIPS analysis the relevant ratio was to 1:37 which is close to the Eco-indicator 99 value.

Figure 2.3 shows an example of application of Eco-indicator technique to determine the environmental impact of a service. The service compared is the transportation of one passenger a distance of one kilometre by bus and by car. Only combustion of fuel was taken into account.

The ratio of environmental impacts of this service was 3.5. The ratio is similar to the results from the more comprehensive comparison made above, for the reason that fuel combustion during use is the major environmental impact in the life cycles of a car and a bus.

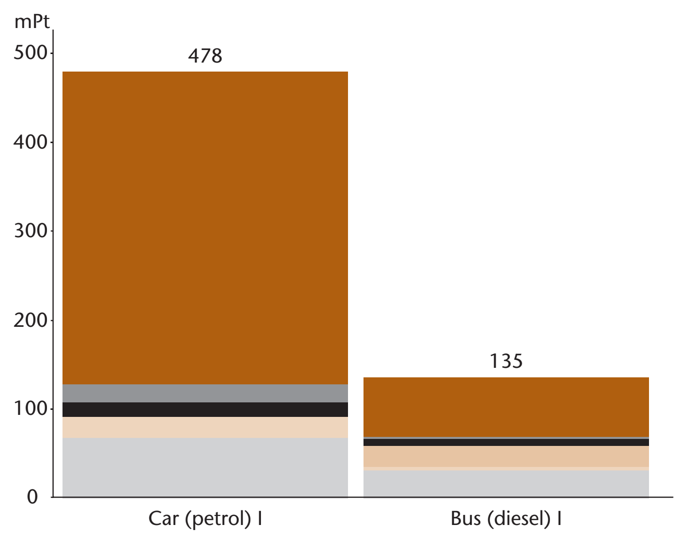


**Figure 2.3** *Environmental indices for transportation of one passenger by car and by bus within a distance of one kilometre. Comparing 2,5E4 m transport 'Car (petrol) I' with 1E3 m transport 'Bus (diesel) I'. Method used: Eco-indicator 99 (H) / Europe Ei 99 H/H/ single score.*

## Eco-indicator 95

A comparative Life Cycle Assessment of the car and the municipal bus was also carried out using the Eco-indicator 95 method. In the Eco-indicator 95 method, contrary to the Eco-indicator 99 approach, there is no impact category for depletion of natural resources; only deterioration of ecosystem quality and human health are taken into consideration.

Figure 4 shows the results obtained with the Eco-indicator 95 method. The ratio of indices is equal here 3.8 (8.66/2.28) to the results with the other methods. The interpretation of the result obtained (why the ratio is less favourable for the bus than in the Eco-indicator 99 method) is difficult. Both methods use different impact categories and different coefficients in the normalisation and weighting phases. That is why it is not feasible to indicate one major reason for the different results in the analyses. The differences in the results obtained reflect the lack of an accepted LCA methodology. The lack of a "resource depletion" impact category in the Eco-indicator 95 approach makes this method less apt to monitor sustainable development. Resource management is important for sustainability.

## Eco-points

The Eco-points method has been one of the first, which enabled the aggregation of the LCA results into a single score. The Eco-points method, however, does not include a classification stage (this is the main methodological difference in relation to the Eco-indicator technique). As a result a set of inflows and outflows containing specific substances is examined separately instead of using impact categories. The disadvantage of this approach is the big number of compounds which have to be taken into account and, as a result, difficulties in the interpretation of the results.

The results of the LCA analysis for the passenger car and the municipal bus performed using the Eco-points method are shown in Figure 2.5. The ratio of environmental indices for life cycles of the two is equal to 5.4 (3.14/0.561). This is also close to the results from the MIPS methodology. The following emissions were found to be the most significant for the environmental profile of the products: $SO_x$, waste, $CO_2$, $NO_x$, and NMVOC (non-methane volatile organic compounds).

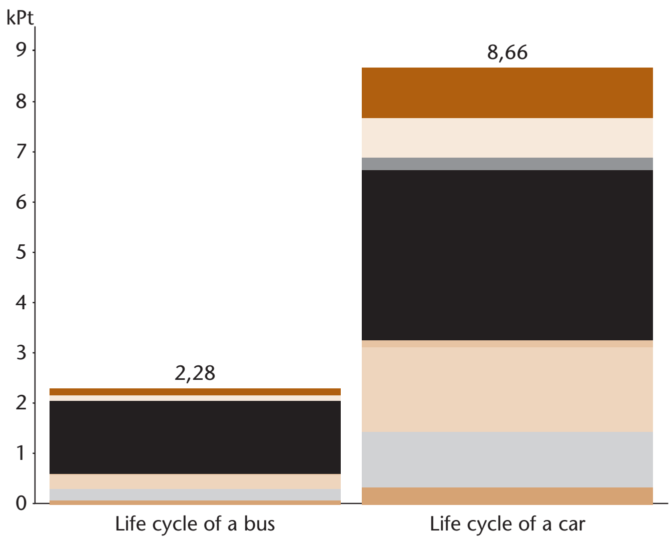


**Figure 2.4** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle 'life cycle of a bus' with 154 p life cycle 'life cycle of a car'. Method used: Eco-indicator 95 / Europe e / single score.*

- Summer smog
- Winter smog
- Carcinogens
- Heavy metals
- Eutrophication
- Solid waste
- Pesticides
- Acidification
- Ozone layer
- Energy resources
- Greenhouse

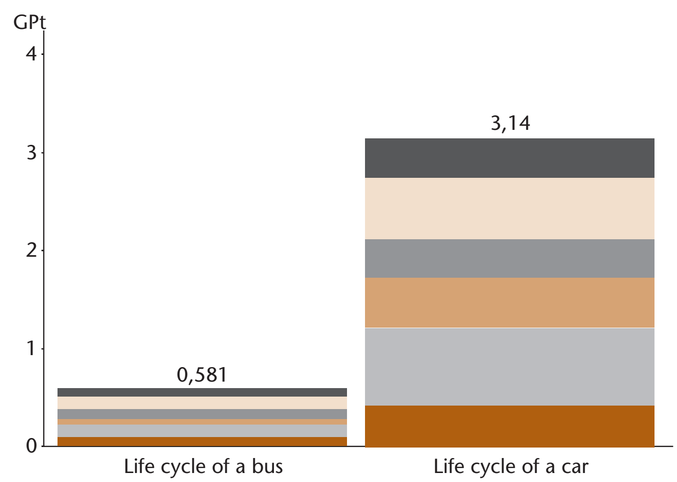


**Figure 2.5** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle 'life cycle of a bus' with 154 p life cycle 'life cycle of a car'. The 5 largest impacts are shown. Other impacts include: Cd; Cu; Dust PM10; Energy; Hg; Metals; $NH_3$; N; Pb and Zn. Method used: Eco-points 97 (CH) / Eco-points / single score.*

- $NO_x$
- $SO_x$
- NMVOC
- $CO_2$
- Waste
- Other impacts

## 4 LCA Analysis According to the EDIP and EPS Methods EDIP\UMIP

Similarly to Eco-indicator 95 the EDIP/UMIP (Environmental Development of Industrial Products, in Danish UMIP) method does not reflect resource depletion in a single score. Is should be stressed that in EDIP the impact category "resources" is used in the characterisation phase, but neglected in the normalisation and weighting phases. Another difference between the EDIP and Eco-indicator 95 methods is the application of different impact categories and different coefficients in normalisation and weighting phases.

The results of an LCA analysis for the car and the bus are shown in Figure 2.6. The ratio of environmental indices for the two life cycles is equal to 4.4 (75.9/17.2). The result obtained is similar to the ratio determined by Eco-indicator 95 (ratio of 3.8). The small difference comes from different coefficients in the normalisation and weighting phases.

According to the EDIP method the main environmental impact is connected with emissions of toxic substances to water (mainly strontium) and soil (mainly benzene) released during petrol production.

### EDIP/UMIP 96

EDIP/UMIP 96 method is a supplement to the basic version of EDIP method shown previously. EDIP 96 assesses natural resource consumption only. This technique allows a detailed analyses of resources depletion. An LCA analysis conducted with the EDIP 96 method determined the major resources consumption in the life cycles of the car and the bus. As can be seen in the Figure 2.7 the biggest impacts in the life cycle of the bus is consumption of crude oil (fuel production), lead (used for building infrastructure), iron (for steel parts) and silver (fuel production). In the life cycle of the car the most decisive contributions come from platinum (used in the catalytic converter), crude oil and silver (fuel production), as well as copper and iron (structural materials).

The ratio of environmental indices for life cycles of the two means of transport is equal to 7.0 (351/50). This result is higher than obtained in previous analyses (3.8 – 5.4) which means that from the point of view of resource consumption the bus is even more environmentally friendly than if all damage categories are taken into account (compare Eco-indicator 95).

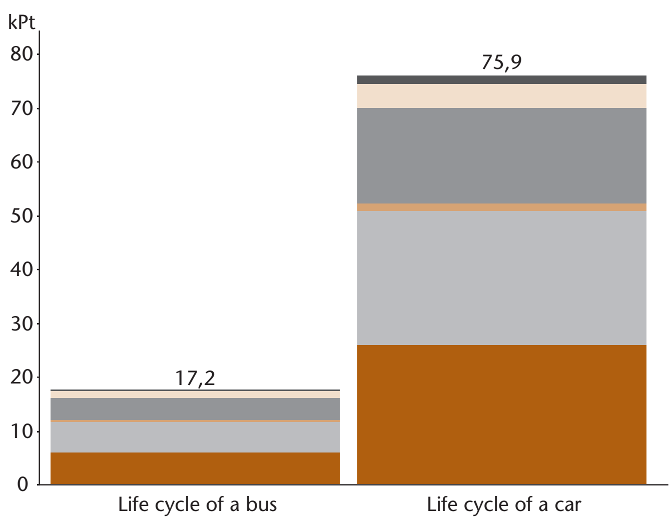


**Figure 2.6** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle 'life cycle of a bus' with 154 p life cycle 'life cycle of a car'. The 5 largest impacts are shown. Other impacts include: acidification; bulk waste; eutrophication; global warming (GWP 100); hazardous waste; human toxicity air; human toxicity water and ozone depletion. Method used: EDIP/UMIP 96 / EDIP World /Dk / single score.*

Ecotoxicity water chronic
Ecotoxicity water acute
Ecotoxicity soil chronic
Human toxicity soil
Slags/ashes
Other impacts

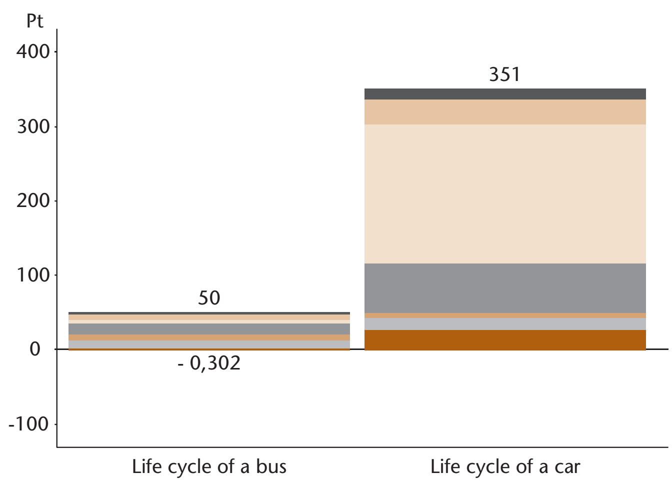


**Figure 2.7** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle 'life cycle of a bus' with 154 p life cycle 'life cycle of a car'. The 6 largest impacts are shown. Other impacts include: aluminium; cadmium; coal; cobolt; gold; manganese; mercury; molybdenum; natural gas; nickel; tin and zinc. Method used: EDIP/ UMIP 96 (resources only) / EDIP World /Dk / single score.*

Copper
Iron
Lead
Oil
Brown coal
Silver
Other impacts

## EPS 2000

The Environmental Priority Strategy, EPS, system expresses the damage to the environment in financial terms. Weighting factors reflect future costs, direct losses, or willingness to pay. This method does not use a normalisation step. The results are shown in Figure 2.8.

The most decisive impact from both car and bus transportation is connected with the depletion of resources and the processes accompanying raw material extraction. The ratio of environmental indices for the life cycles of both the car and the bus is equal to 17.5 (14.7/0.841). This differs significantly from the results obtained with the other techniques. It should be emphasised, however, that the result in this case is highly dependent on arbitrary assumed equivalence factors of selected materials. For example if we use nickel in the catalytic converter of the bus or car instead of platinum the ratio of the single scores drops from 17.5 to 4.65.

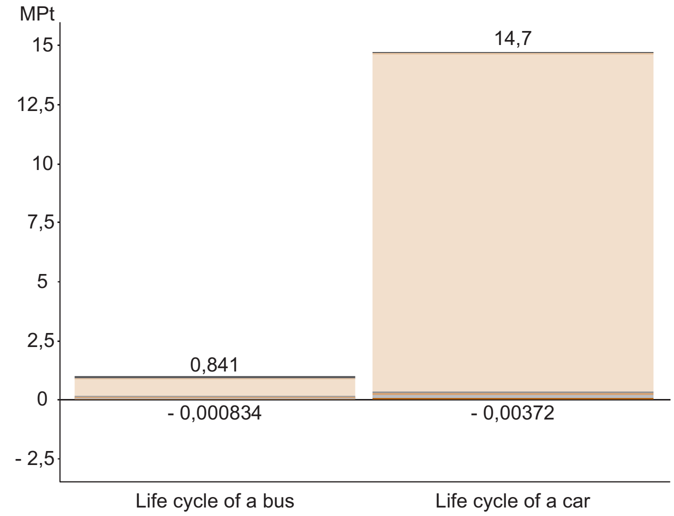


**Figure 2.8** *Environmental indices for LCA analysis of a passenger car and municipal bus. Comparing 1 p life cycle 'life cycle of a bus' with 154 p life cycle 'life cycle of a car'. The 6 largest impacts are shown. Other impacts include: Crop Growth Capacity; Morbidity; Nuisance; Prod. Cap. Drinking water; Prod. Cap. Irrigation Water; Severe Nuisance and Wood Growth Capacity. Method used: EPS 2000 / EPS / single score.*



## 5 Conclusions

The results of the comparison of LCA data obtained with different methods (Eco-indicator, Eco-points, EPS, MIPS etc.) are comparable. The small differences between the ratios of environmental indices are astonishing. Still the similarity of the results indicates that all the applied techniques are all well used, verified and relatively reliable.

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# LCA 3 A Comparative Study on Single-use and Returnable Milk Packaging using an Economic Input/Output LCA Model

## 1 Background

### Economic input/output Models (LCA on line)

Although Life Cycle Assessment does not involve advanced mathematics analysing a life cycle from cradle-to-grave requires extensive mathematical calculations balancing several hundreds of different inputs and outputs. A professional full scale LCA software is complicated with extensive modelling facilities and databases.

Nevertheless, it is also feasible to run LCA using other evaluation techniques. One such quantitative technique is the Economic Input-Output Life Cycle Assessment, EIO-LCA, developed by a team of researchers of the Green Design Initiative at Carnegie Mellon University, Pittsburgh, USA. The software is available at *(http://www.eiolca.net)*. Eiolca.net was designed to enable simple and quick LCA instead of conducting a detailed analysis recommended by ISO standards, which requires considerable attention, time and experience.

Eiolca.net uses the so-called economic input/output models developed by Wassily Leontief over fifty years ago. The entire economy of the country (here USA only) is divided into about 500 distinct economic sectors. Each sector is represented by one row and one column in a matrix which describes the total sales from one sector to other sectors, purchases from one sector, or the amount of purchases from one sector to produce a dollar of output for the sector. The model takes into consideration all the processes needed to obtain a certain product or provide a certain service (e.g. mining, transportation, or manufacturing). In order to assess the entire life cycle, all the lifetime stages have to be modelled separately.

This commodity-to-commodity economic input/output model is derived from statistics at the Department of Commerce, USA. The Eiolca.net software identifies the economic and environmental impacts as a result of a purchase from a particular sector. However, it should be stressed, Eiolca.net as any other LCA software, contains numerous sources of uncertainty including old, incomplete or missing data developed from a variety of public data sets and assembled for various commodity sectors.

### Two Kinds of Milk Packaging

The comparative analysis of two kinds of milk packaging – a returnable glass bottle and a non-returnable plastic bag – shown here was conducted as a course project. (The results of the analysis can not be used externally, e.g. for commercials or marketing claims.)

The functional unit was defined as the packaging of 1 million $m^3$ of milk to fit into the unit in which input data is expressed, namely million US Dollars (mln USD).

To pack 1 million $m^3$ of milk, 1 billion of one litre plastic, polyethylene, bags or 100 million of one litre glass bottles being used 10 times before being wasted is needed. We thus assume that the glass bottles are washed once and then returned, washed and refilled 9 times, to be used a total of 10 times. The polyethylene bags cost 13,5 mln USD (0.0135 USD per bag), and the bottles 7,7 mln USD (0.077 USD per bottle). Additionally, the returnable packaging needs extra amount of transportation (0,3 mln USD) and washing (0,3 mln USD).

The data collected had Polish prices. These were converted into dollars according to the current exchange rate. The Eiolca.net analysis used the prices from 1992.

Despite uncertainties in connection with data collection, the final outcome of an analysis, as a ratio between environmental profiles, has been judged to be reliable enough to indicate which alternative is more environmentally friendly.

## 2 Single Use Milk Packaging (Plastic bag)

### Economic Turnover

The economic turnover generated by the production of 1 billion plastic bags for a cost of 13.5 mln USD is shown in Table 3.1. The total economic flow for the complete supply chain of purchases needed is 33.52 mln USD. (The production creates a value in all supply chains far above the costs of the plastic bags themselves). The largest values are found in the “Plastics materials and resins” sector (13.94 mln USD) but also in the “Industrial inorganic and organic chemicals” sector (6.11 mln USD), “Wholesale trade” (1.39 mln USD), and “Crude petroleum and natural gas” (1.21 mln USD). Only the main sectors are shown in the table.

### Environmental Impact

The activity in so many sectors must result in the generation of substantial material and energy flows, which in turn produces a significant environmental load.

Table 3.2 shows selected material and energy flows associated with the production of 1 million plastic bags in “Plastic materials and resins” sector. The data in the table shows that 302.8 t of conventional pollutants are released, 27,988 t of greenhouse gases expressed as $CO_2$ equivalents released, 6,957 t of hazardous waste generated, 5,476 t of ores used, etc.

### Health, Work Safety, and Employment

Special attention is directed towards the OSHA Safety and Employment data. Table 3.3 shows the estimated health effects for workers across the supply chain for the created output in the economy. The data displayed in the table include fatalities (Fatalities = number of occupational injuries resulting in a death), and Lost Workday Cases (LCW = an incident where an employee experiences variable days away from work or is restricted in work activity due to an injury or illness on the job). Data were obtained from U.S. BLS (Bureau of Labour Statistics), 1994, and Survey of Occupational Injuries and Illnesses 1992, Washington D.C., U.S. Department of Labour.

Employment represents the number of jobs created across the supply chain. Thus the purchase of 1 billion plastic bags creates about 150 jobs (note that the cost to create one job is here about 100,000 USD (!)).

**Table 3.1 Economic turnover generated by the production of 1 billion plastic bags.** *Data are shown for all sectors and for each of the 11 largest sectors.*

| Sector | Costs (mln USD) |
|---|---|
| Total for all sectors | 33.52 |
| Plastics materials and resins | 13.94 |
| Industrial inorganic and organic chemicals | 6.11 |
| Wholesale trade | 1.39 |
| Crude petroleum and natural gas | 1.21 |
| Miscellaneous plastics products, n.e.c. | 0.8069 |
| Electric services (utilities) | 0.629 |
| Trucking and courier services, except air | 0.6199 |
| Natural gas distribution | 0.4195 |
| Other repair and maintenance construction | 0.3881 |
| Petroleum refining | 0.3232 |
| All other sectors | 7.68 |

**Table 3.2 Material and energy flows generated by production of 1 billion plastic bags.**

| Effects | Total for all sectors |
|---|---|
| Economic Purchases (mln USD) | 33.52 |
| Electricity Used (Mkw-hr) | 16.17 |
| Energy Used (TJ) | 431.1 |
| Conventional Pollutants Released (metric tons) | 302.8 |
| OSHA Safety (fatalities) | 0.009156 |
| Greenhouse Gases Released (metric tons – $CO_2$ equivalents) | 27988 |
| Fertilizers Used (mln USD) | 0.02640 |
| Fuels Used (Terajoules) | 413.1 |
| Ores Used – at least (metric tons) | 5476 |
| Hazardous Waste Generated (RCRA, metric tons) | 6957 |
| External Costs Incurred (median, mln USD) | 0.6710 |
| Toxic Releases and Transfers (metric tons) | 76.69 |
| Weighted Toxic Releases and Transfers (metric tons) | 71.47 |
| Water Used (billion gallons) | 0.3368 |

## Emissions to the Air

Table 3.4 shows the estimated amounts of conventional pollutants emitted in connection with the analysed economic supply chain in the 10 top sectors. The total load is 302.8 tons. $SO_2$ and $NO_2$ are the major pollutants, with 89.43 t and 89.94 t respectively. The largest amounts of $SO_2$ and $NO_2$ come from the "Electric services (utilities)" sector, while the second biggest polluter is the "Industrial inorganic and organic chemicals" sector with 18.93 t of $SO_2$ and 15.62 t of $NO_2$ emitted.

Table 3.5 shows emission of greenhouse gasses as a result of production of 1 billion of plastic bags for milk packaging. The total emission of $CO_2$ from all sectors is equal to 25,429 t. It is worth noting the substantial emissions of methane, 2,053 t. Most of the releases come from 3 sectors: "Electric services (utilities)", "Plastics materials and resins" and "Industrial inorganic and organic chemicals".

**Table 3.3 Estimation of workers health and safety, and creation of jobs across the plastic bag supply chain (1 billion plastic bags).**
*(LWC=Lost Workday Cases, Employment= number of jobs.) Data are shown for all sectors and for each of the 11 largest sectors.*

| Sector | Fatalities | LWC | Employment |
|---|---|---|---|
| Total for all sectors | 0.009156 | 4.882 | 147.6 |
| Trucking and courier services, except air | 0.001813 | 0.4561 | 7.227 |
| Crude petroleum and natural gas | 0.001119 | 0.1076 | 2.906 |
| Plastics materials and resins | 0.000808 | 0.9876 | 27.28 |
| Other repair and maintenance construction | 0.000773 | 0.1667 | 2.030 |
| Wholesale trade | 0.000626 | 0.5155 | 15.95 |
| Industrial inorganic and organic chemicals | 0.000379 | 0.3836 | 10.54 |
| Railroads and related services | 0.000243 | 0.09592 | 0.1637 |
| Logging | 0.000229 | 0.009425 | 0.1307 |
| Miscellaneous plastics products, n.e.c. | 0.000191 | 0.4007 | 7.789 |
| Water transportation | 0.000188 | 0.0269 | 0.5728 |

**Table 3.4 Emission of toxic gases generated by production of 1 billion plastic bags (metric tons).**
*(Lead – Lead particulate emissions to air; PM10 = Particulate Matter, less than 10 microns in diameter.)*

| Sector | $SO_2$ | CO | $NO_2$ | VOC | Lead | PM10 |
|---|---|---|---|---|---|---|
| Total for all sectors | 89.43 | 71.73 | 89.94 | 37.88 | 0.01823 | 13.84 |
| Electric services (utilities) | 43.14 | 1.383 | 21.12 | 0.1726 | 0.001014 | 1.090 |
| Industrial inorganic & organic chemicals | 18.93 | 16.65 | 15.62 | 10.33 | 0.01133 | 1.867 |
| Plastics materials and resins | 13.22 | 5.816 | 12.305 | 16.48 | 0.000125 | 1.525 |
| Crude petroleum & natural gas | 2.372 | 1.652 | 3.986 | 1.181 | 0.0 | 0.04789 |
| Petroleum refining | 1.039 | 0.9381 | 0.6515 | 0.5152 | 0.000005 | 0.07316 |
| Nitrogen & phosphate fertilizers | 1.009 | 0.3085 | 0.9975 | 0.1510 | 0.0 | 0.1514 |
| Paper and paper board mills | 0.9838 | 1.0164 | 0.6009 | 0.2607 | 0.000018 | 0.1568 |
| Natural gas distribution | 0.8801 | 0.7797 | 0.4297 | 0.01592 | 0.000000 | 0.002208 |
| Railroads and related services | 0.8177 | 1.728 | 6.188 | 0.3534 | 0.000000 | 0.3532 |
| Blast furnaces and steel mills | 0.7608 | 2.443 | 0.2329 | 0.08903 | 0.000348 | 0.14 |

**Table 3.5 Emission of greenhouse gases generated by production of 1 billion plastic bags.**
*Data are expressed as metric tons of $CO_2$ equivalents. GWP = Global Warming Potential is the sum expressed as metric tons of $CO_2$ equivalents.*

| Sector | Sum GWP | $CO_2$ | $CH_4$ | $N_2O$ | CFCs |
|---|---|---|---|---|---|
| Total for all sectors | 27988 | 25420 | 2053 | 15.61 | 499.1 |
| Electric services (utilities) | 8551 | 7651.8 | 897.7 | 1.703 | 0.0 |
| Plastics materials and resins | 7498 | 70256 | 388.56 | 4.6256 | 78.90 |
| Industrial inorganic and organic chemicals | 6632 | 5859 | 360.2 | 3.399 | 409.7 |
| Trucking and courier services, except air | 1035 | 930.8 | 102.9 | 1.779 | 0.0 |
| Nitrogenous and phosphatic fertilizers | 745.0 | 715.0 | 34.560 | 0.4372 | 0.0 |
| Petroleum refining | 281.0 | 269.4 | 10.82 | 0.1603 | 0.655 |
| Wholesale trade | 267.3 | 241.8 | 25.06 | 0.4979 | 0.0 |
| Water transportation | 254.19 | 236.0 | 17.98 | 0.2125 | 0.0 |
| Railroads and related services | 250.2 | 231.9 | 18.18 | 0.1707 | 0.0 |
| Air transportation | 231.1 | 205.99 | 24.90 | 0.2328 | 0.0 |

## 3 Returnable Milk Packaging (Glass bottle)

### The Glass Bottles

To compare the environmental impacts of plastic bags and returnable glass bottles for milk packaging, a similar analysis was made for the production of 100 million glass bottles bought for 7.7 mln USD. In addition an analysis was made on the transportation (0.3 mln USD) and washing (0.3 mln USD) needed to use the glass bottles a total of ten times.

The results of calculations are presented in Tables 3.6-3.14.

### Economic Turnover

The economic turnover generated by the production of 100 million glass bottles for 7.76 mln USD is estimated to be 15.05 mln USD. This is about 2 times less than for plastic bags. In this case, we may also expect smaller environmental impact.

### Environmental Impact

The estimated environmental impact caused by the production of 100 million glass bottles is shown in Table 3.6. The amount of pollutants generated is estimated to be 177.7 t conventional pollutants (302.8 t for the plastic bags, Table 3.2), 19,313 t of greenhouse gases expressed in $CO_2$ equivalents – 70% less than for plastic bags – 470.1 t of hazardous waste (15 times smaller than for plastic bags!). Resource use data included e.g. 549.6 t of ores (10 times smaller than for plastic bags!).

### Health, Work Safety, and Employment

The effects on workers health, safety and employment of the production of 100 million glass bottles are shown in Table 3.7. The number of fatalities is about twice as low as for disposal

**Table 3.6 Material and energy flows generated by production of 100 million glass bottles.**

| Effects | Total for all sectors |
|---|---|
| Economic Purchases (mln USD) | 15.05 |
| Electricity Used (Mkw-hr) | 9.192 |
| Energy Used (TJ) | 247.8 |
| Conventional Pollutants Released (metric tons) | 177.7 |
| OSHA Safety (fatalities) | 0.004168 |
| Greenhouse Gases Released (metric tons – $CO_2$ equivalents) | 19313 |
| Fertilizers Used (mln USD) | 0.002611 |
| Fuels Used (Terajoules) | 237.6 |
| Ores Used – at least (metric tons) | 549.6 |
| Hazardous Waste Generated (RCRA, metric tons) | 470.1 |
| External Costs Incurred (median, mln USD) | 0.5014 |
| Toxic Releases and Transfers (metric tons) | 4.460 |
| Weighted Toxic Releases and Transfers (metric tons) | 15.91 |
| Water Used (billion gallons) | 0.05065 |

packaging (Table 3.3) while number of new jobs is estimated to be 86.4.

## Emissions to the Air

Table 3.8 shows the amounts of pollutants emitted in the 10 top economic sectors. The total load is calculated as 177.7 t. (Table 3.6). Just as for the plastic bags, $SO_2$ and $NO_2$ are the major pollutants with 57.18 t and 74.44 t respectively. The largest amounts of $SO_2$ and $NO_2$ emissions come from the "Electric services (utilities)" sector and the "Glass containers" sector. Both total and local emissions are smaller than the corresponding values for the production of disposal packaging (compare Table 3.4).

Table 3.9 shows emission of greenhouse gasses as a result of the production of 100 million glass bottles. The total emission of $CO_2$ from all sectors is equal to 17,532 t (about 70% of the emission for the plastic bags). Table 3.9 shows substantial emissions of methane, 1,742 t (only 15% less than for the plastic bags) coming from the "Glass containers" and the "Electric services (utilities)" sectors (compare Table 3.5).

**Table 3.7 Estimation of workers health and safety, and creation of jobs across the glass bottle supply chain (100 million glass bottles).** *(LWC=Lost Workday Cases, Employment= number of jobs.) Data are shown for all sectors and for each of the 11 largest sectors.*

| Sector | Fatalities | LWC | Employment |
|---|---|---|---|
| Total for all sectors | 0.004168 | 5.77 | 86.4 |
| Trucking and courier services, except air | 0.000825 | 0.208 | 3.3 |
| Other repair and maintenance construction | 0.000377 | 0.0814 | 0.991 |
| Logging | 0.000366 | 0.0151 | 0.209 |
| Crude petroleum and natural gas | 0.000275 | 0.0265 | 0.715 |
| Wholesale trade | 0.000231 | 0.190 | 5.89 |
| Sand and gravel | 0.000213 | 0.0426 | 1.15 |
| Paper board containers and boxes | 0.000198 | 0.3277 | 5.636 |
| Coal | 0.000173 | 0.0434 | 0.423 |
| Railroads and related services | 0.000168 | 0.0662 | 0.113 |
| Water transportation | 0.000106 | 0.0152 | 0.322 |

**Table 3.8 Emission of toxic gases generated by production of 100 million glass bottles (metric tons).** *(Lead – Lead particulate emissions to air; PM10 = Particulate Matter, less than 10 microns in diameter.)*

| Sector | $SO_2$ | CO | $NO_2$ | VOC | Lead | PM10 |
|---|---|---|---|---|---|---|
| Total for all sectors | 57.18 | 26.42 | 74.44 | 7.010 | 0.003860 | 12.61 |
| Electric services (utilities) | 27.67 | 0.887 | 13.5 | 0.1107 | 0.000651 | 0.6993 |
| Glass containers | 19.19 | 2.77 | 39.89 | 1.21 | 0.000432 | 7.455 |
| Paper and paper board mills | 2.632 | 2.72 | 1.601 | 0.6974 | 0.000048 | 0.42 |
| Industrial inorganic and organic chemicals | 1.341 | 1.18 | 1.107 | 0.7317 | 0.000803 | 0.1322 |
| Lime | 0.9195 | 0.5868 | 1.048 | 0.01524 | 0.000005 | 0.3032 |
| Pulp mills | 0.6441 | 0.8888 | 0.4907 | 0.2226 | 0.000018 | 0.1345 |
| Natural gas distribution | 0.6305 | 0.5585 | 0.3078 | 0.0114 | 0.0 | 0.001582 |
| Crude petroleum and natural gas | 0.5838 | 0.4066 | 0.9812 | 0.2908 | 0.0 | 0.01179 |
| Railroads and related services | 0.56442 | 1.192 | 4.272 | 0.244 | 0.0 | 0.2439 |
| Petroleum refining | 0.4248 | 0.3835 | 0.2663 | 0.2107 | 0.000002 | 0.0299 |

**Table 3.9 Emission of greenhouse gases generated by production of 100 million glass bottles.**
*Data are expressed as metric tons of $CO_2$ equivalents. GWP = Global Warming Potential is the sum expressed as metric tons of $CO_2$ equivalents.*

| Sector | GWP | $CO_2$ | $CH_4$ | $N_2O$ | CFCs |
|---|---|---|---|---|---|
| Total for all sectors | 19313 | 17532 | 1742 | 8.861 | 31.16 |
| Glass containers | 10394 | 9490 | 899.7 | 4.578 | 0.0 |
| Electric services (utilities) | 5484 | 4908 | 575.78 | 1.092 | 0.0 |
| Paper and paper board mills | 501.4 | 461.0 | 40.12 | 0.2385 | 0.0 |
| Trucking and courier services, except air | 471.4 | 423.7 | 46.86 | 0.8097 | 0.0 |
| Industrial inorganic and organic chemicals | 469.9 | 415.1 | 25.52 | 0.2408 | 29.02 |
| Lime | 250.9 | 228.9 | 21.95 | 0.1174 | 0.0 |
| Railroads and related services | 172.7 | 160.0 | 12.55 | 0.1179 | 0.0 |
| Water transportation | 143.0 | 132.7 | 10.12 | 0.12 | 0.0 |
| Natural gas distribution | 139.6 | 132.9 | 6.606 | 0.08924 | 0.0 |
| Paper board containers and boxes | 135.6 | 122.9 | 12.51 | 0.1787 | 0.0 |

## Transportation of Returnable Packaging (Glass bottle)

To have a full environmental profile of the environmental impact of the returnable glass bottles, the effects of transportation (cost 0.3 mln USD) of 100 million bottles ten times must be estimated. The total economic turnover in the sectors caused by transport was estimated to be 0.4193 mln USD.

The emissions due to transport (Table 3.10) are estimated as 42.3 t conventional pollutants, 93.82 t $CO_2$ equivalents of greenhouse gases, 4.6 t of hazardous waste generated, and 11.8 t of ores used.

Table 3.11 shows the amounts of pollutants emitted in connection with transportation of returnable glass bottles in the 10 top economic sectors. CO and $NO_2$ (from fuel combustion) are the major contributors in total emission of toxic substances. 98% of the emissions of CO and $NO_2$ comes from the "Petroleum, natural gas, and solid mineral exploration" sector.

Table 3.12 shows emission of greenhouse gases as a result of transportation of 100 million glass bottles. The total emissions of $CO_2$ equivalents are relatively low (85.47 t) due to the small currency flow in the economic chain (0.3 mln USD).

An analysis of the OSHA Safety and Employment data (not shown – try to make this calculations on your own) for the sector "Transportation" revealed that 1.4 new jobs will be created in connection with 10 trips of 100 million glass bottles.

**Table 3.10 Material and energy flows generated by transportation of 100 million glass bottles.**

| Effects | Total for all sectors |
|---|---|
| Economic Purchases (mln USD) | 0.4193 |
| Electricity Used (Mkw-hr) | 0.03184 |
| Energy Used (TJ) | 1.2 |
| Conventional Pollutants Released (metric tons) | 42.3 |
| OSHA Safety (fatalities) | 0.000294 |
| Greenhouse Gases Released (metric tons CO2 equivalents) | 93.82 |
| Fertilizers Used (mln USD) | 0.000092 |
| Fuels Used (Terajoules) | 1.16 |
| Ores Used – at least (metric tons) | 11.8 |
| Hazardous Waste Generated (RCRA, metric tons) | 4.6 |
| External Costs Incurred (median, mln USD) | 0.0921 |
| Toxic Releases and Transfers (metric tons) | 0.05121 |
| Weighted Toxic Releases and Transfers (metric tons) | 0.1938 |
| Water Used (billion gallons) | 0.000411 |

## Washing of Returnable Packaging (Glass bottle)

Similarly an analysis was carried out for the washing of 100 million glass bottles 10 times (cost 0.3 mln USD). Results of the calculations are shown in Tables 3.13 and 3.14. The total economic turnover generated in all sectors is 0.6288 mln USD.

6.46 t of pollutants are emitted, the lowest in this analysis, while greenhouse gases release, 338.4 t of $CO_2$ equivalents, is relatively high. This is apparently due to the combustion of fuels when heating the water for washing.

**Table 3.11 Conventional pollutants generated by transportation of 100 million glass bottles.**
*(10 top sectors are displayed in metric tons).*

| Sector | $SO_2$ | CO | $NO_2$ | VOC | Lead | PM10 |
|---|---|---|---|---|---|---|
| Total for all sectors | 0.39 | 6.88 | 7.246 | 0.461 | 0.000080 | 27.37 |
| Electric services (utilities) | 0.2192 | 0.007027 | 0.1073 | 0.000877 | 0.000005 | 0.005539 |
| Petroleum, natural gas, and solid mineral exploration | 0.0680 | 6.633 | 7.002 | 0.4095 | 0.0 | 27.33 |
| Blast furnaces and steel mills | 0.0304 | 0.0976 | 0.009308 | 0.003557 | 0.000014 | 0.005592 |
| Petroleum refining | 0.0180 | 0.01625 | 0.01128 | 0.008923 | 0.0 | 0.001267 |
| Crude petroleum and natural gas | 0.01114 | 0.007761 | 0.01873 | 0.00555 | 0.0 | 0.000225 |
| Industrial inorganic and organic chemicals | 0.006846 | 0.006021 | 0.005648 | 0.003735 | 0.000004 | 0.000675 |
| Explosives | 0.006754 | 0.000714 | 0.002853 | 0.002477 | 0.0 | 0.000369 |
| Natural gas distribution | 0.005959 | 0.005279 | 0.002909 | 0.000108 | 0.0 | 0.000015 |
| Primary nonferrous metals, n.e.c. | 0.003069 | 0.001705 | 0.000123 | 0.000017 | 0.000043 | 0.000073 |
| Nitrogenous and phosphatic fertilizers | 0.002386 | 0.000729 | 0.002358 | 0.000357 | 0.0 | 0.000358 |

**Table 3.12 Emission of greenhouse gases generated by transportation of 100 million glass bottles.**
*Data are expressed as metric tons of $CO_2$ equivalents. GWP = Global Warming Potential is the sum expressed as metric tons of $CO_2$ equivalents.*

| Sector | GWP | $CO_2$ | $CH_4$ | $N_2O$ | CFCs |
|---|---|---|---|---|---|
| Total for all sectors | 93.82 | 85.47 | 8.112 | 0.0505 | 0.1836 |
| Electric services (utilities) | 43.45 | 38.88 | 4.561 | 0.008653 | 0.0 |
| Petroleum, natural gas, and solid mineral exploration | 19.232 | 17.86 | 1.3625 | 0.0140 | 0.0 |
| Blast furnaces and steel mills | 7.985 | 7.403 | 0.5777 | 0.003531 | 0.0 |
| Petroleum refining | 4.867 | 4.665 | 0.1873 | 0.002776 | 0.01135 |
| Industrial inorganic and organic chemicals | 2.398 | 2.119 | 0.1303 | 0.001229 | 0.148 |
| Air transportation | 2.317 | 2.065 | 0.2498 | 0.002334 | 0.0 |
| Nitrogenous and phosphate fertilizers | 1.773 | 1.690 | 0.08177 | 0.001033 | 0.0 |
| Trucking and courier services, except air | 1.640 | 1.47 | 0.163 | 0.002817 | 0.0 |
| Natural gas distribution | 1.319 | 1.256 | 0.06244 | 0.000843 | 0.0 |
| Lubricating oils and greases | 0.9533 | 0.9189 | 0.0339 | 0.000501 | 0.0 |

Table 3.14 shows the amounts of pollutants emitted in connection with washing of returnable milk packaging, glass bottles, in the 10 top sectors. CO and $NO_2$ (from fuel combustion) are the major contributors to the total emission of toxic substances. Most of the emissions of CO and $NO_2$, which are significantly lower than for transportation, comes from “Water supply and sewerage systems” and “Electric services (utilities)” sectors.

The OSHA Safety and Employment data (not shown) concludes that for sector “Washing”, 13.5 new jobs will be created.

## 4 Conclusions

### The Comparison of Returnable and Non-returnable Packaging

The results of the Economic Input-Output Life Cycle Assessment analysis are summarised in Table 3.15. The table compares the environmental impacts caused by the production of 1 billion plastic bags, compared to the production and tenfold use (causing transportation and washing ten times) of 100 million glass bottles for milk packaging.

The table shows that in all analysed categories the use of returnable glass bottles are superior to single plastic bags. Conventional pollutant and greenhouse gases release is about 30% lower for returnable packaging. Moreover, resources use, expressed as amount of ores used and hazardous waste generated, is 9 to 14 (!) times lower for the returnable milk packaging.

**Table 3.13 Material and energy flows generated by washing of 100 million glass bottles 10 times.**

| Effects | Total for all sectors |
|---|---|
| Economic Purchases (mln USD) | 0.6288 |
| Electricity Used (Mkw-hr) | 0.1362 |
| Energy Used (TJ) | 3.89 |
| Conventional Pollutants Released (metric tons) | 6.46 |
| OSHA Safety (fatalities) | 0.000289 |
| Greenhouse Gases Released (metric tons $CO_2$ equivalents) | 338.4 |
| Fertilizers Used (mln USD) | 0.000150 |
| Fuels Used (Terajoules) | 3.741 |
| Ores Used – at least (metric tons) | 25.95 |
| Hazardous Waste Generated (RCRA, metric tons) | 10.8 |
| External Costs Incurred (median, mln USD) | 0.0118 |
| Toxic Releases and Transfers (metric tons) | 0.125 |
| Weighted Toxic Releases and Transfers (metric tons) | 0.898 |
| Water Used (billion gallons) | 0.000604 |

**Table 3.14 Conventional pollutants emission generated by washing of 100 million glass bottles 10 times.**
*(10 top sectors are displayed in metric tons).*

| Sector | $SO_2$ | CO | $NO_2$ | VOC | Lead | PM10 |
|---|---|---|---|---|---|---|
| Total for all sectors | 1.94 | 1.435 | 1.956 | 0.5388 | 0.000343 | 0.5927 |
| Electric services (utilities) | 1.126 | 0.0361 | 0.551 | 0.004503 | 0.000026 | 0.0285 |
| Water supply and sewerage systems | 0.5769 | 0.7146 | 0.847 | 0.39 | 0.000148 | 0.0812 |
| Petroleum refining | 0.0254 | 0.0229 | 0.0159 | 0.0126 | 0.0 | 0.001786 |
| Crude petroleum and natural gas | 0.02383 | 0.0166 | 0.04 | 0.0119 | 0.0 | 0.000481 |
| Cement, hydraulic | 0.02293 | 0.007878 | 0.02383 | 0.001513 | 0.000001 | 0.004591 |
| Natural gas distribution | 0.020391 | 0.01806 | 0.009955 | 0.000369 | 0.03 | 0.000051 |
| Blast furnaces and steel mills | 0.0194 | 0.0622 | 0.005928 | 0.002266 | 0.000009 | 0.003562 |
| Lime | 0.0183 | 0.0117 | 0.02086 | 0.000303 | 0.03 | 0.006035 |
| Industrial inorganic and organic chemicals | 0.01668 | 0.01467 | 0.0138 | 0.0091 | 0.000010 | 0.001645 |
| Primary nonferrous metals, n.e.c. | 0.009019 | 0.005011 | 0.000362 | 0.000049 | 0.000127 | 0.000216 |

**Table 3.15 Comparison of selected environmental impacts for single use (plastic bag) and returnable milk packaging (glass bottle).**

| Effect | 1 bln non-returnable plastic bags | 100 mln glass bottles used ten times |
|---|---|---|
| Energy Used (TJ) | 431.1 | 252.9 |
| Conventional Pollutants Released (metric tons) | 302.8 | 226.4 |
| Greenhouse Gases Released (metric tons $CO_2$ equivalents) | 27,988 | 19,745 |
| Ores Used – minimum value (metric tons) | 5476 | 587 |
| Hazardous Waste Generated (RCRA, metric tons) | 6957 | 486 |
| Employment | 147 | 101 |

The only advantage of the production of single use milk packaging is the generation of more new jobs (about 147) than for returnable milk packaging (about 101) across the two supply chains in the economy. The comparison of the environmental profiles of the two alternatives, however, indicates clearly that the use of returnable milk packaging is the more environmentally friendly alternative.

So, let us buy milk in returnable packaging!

A similar analysis might be easy to perform for any kind of process or service. The on-line software and database for Economic Input-Output Life Cycle Assessment *(http://www.eiolca.net)* are strongly recommended.

## Contacts


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# CA4 An LCA Feasibility Study of a System – the GreenPower-45 Wind Turbine

## 1 Background and General Description

### A Wind Farm with the GreenPower-45 Wind Turbine

A public body has the responsibility for formulating and implementing a plan to manage a 25 MW wind farm nearby a city (1-3 km) with a population of about 20,000 people. Policy decision has been taken, concerning financial, economical and environmental issues. The GreenPower-45 wind turbine Company is offered to set up the wind farm.

The GreenPower-45 wind turbine is a wind energy conversion system with a rotor diameter of 45 m and a rated electrical power output of 1 MW. The hub height is 60 m. Several prototypes are in operation to analyse and study their capabilities.

The annual energy output of the turbine was estimated to about 2.2 GWh when situated in North European coastal areas and assuming an availability of 95%. An overview of the turbine is shown in Figure 4.2 and more details of the tower top, the nacelle and the hub in Figure 4.3. The main characteristics of the turbine are given in Table 4.1.

The first GreenPower-45 wind turbine was put into operation in North Holland in 1985. In the early phase of operation, the owner carried out an extensive measurement program during start-up and the first six months of operation. They collected and reported operating experiences, failure data, and energy production from the beginning of the operation. An inventory was made of the information available and over 200 pieces of documentation were produced, including notices and drawings.

**Figure 4.1 Middelgrunden wind farm.** *The largest offshore wind farm in the world, of the cost of Denmark. Photo: LM Glasfiber.*

## 2 The Life Cycle Assessment Procedure

### Goal Definition and Scope

Within this project, the emphasis is on analysing and improving the cost-effectiveness and environmental impact of the GreenPower-45 wind turbine. The following steps were made to get a clear overview of GreenPower-45:

- Collection of information (see below *Operational, Cost and Environmental data of the GreenPower-45 Wind Farm*).
- Description of specifications and main characteristics.
- Identification of main issues (e.g. hot spots).
- Description of the wind turbine life cycle.
- Estimation of cost versus profit and environmental impact.

### Inventory Analysis

As part of the project, data were collected and a procedure for the analysis was set up. The steps which carried out to provide the project data are:

1. Determination of sources of information to be used.
2. Define entities to be compiled.
3. Define database format.
4. Develop guidelines for filling in database.
5. Compile actual data.

**Table 4.1** *Main characteristics of GreenPower-45.*

| Parameter | Value | Unit |
|---|---|---|
| **General Turbine Data** | | |
| Blade span | 22.50 | m |
| Number of blades | 2 | |
| Tower height | 60 | m |
| Tower radius at hub height | 2.8 | m |
| Distance from hub to tower axis | 6.12 | m |
| Tilt angle | 5.0 | deg |
| Cone angle of the blades | 0.0 | deg |
| Spanwide position of the blade root | 0.964 | m |
| Spanwide position of die pitch bearing | 0.964 | m |
| **General Rotor Data** | | |
| Swept area of the rotor | 1590.4 | $m^2$ |
| Solidity of the rotor | 0.0467 | |
| Moment of inertia w.r.t. rotor axis | 915000.0 | $kgm^2$ |
| **General Blade Data** | | |
| Mass of blade, including tip mass and flange | 4892 | kg |
| Spanwide position of the blade mass centre (w.r.t. rotor axis, including flange) | 7.6 | m |
| Tip moment of inertia about pitch axis | 326.0 | $kgm^2$ |
| 1st flap | 0.94 (0rpm); 1.31 (45rpm) | Hz |
| 2nd flap | 3.95 | Hz |
| 1st lead-lag | 1.78 | Hz |
| 2nd lead-lag | 8.45 | Hz |
| 1st torsion | 18.5 | Hz |
| **Transmission & Generator Data** | | |
| Rated power of generator | 1000 | kW |
| Rated rotor speed | 45 | rpm |
| **Dynamic Properties of the Tower** | | |
| Nacelle mass | 60000.0 | kg |
| 1st bending | 0.36 | Hz |
| Tower Mass | 80000.0 | kg |
| **Aerodynamic Properties** | | |
| Profile | NASA.LS417/ NASA.LS421 | n.a. |
| Maximum lift coefficient | 1.611.5 | n.a. |
| Maximum drag coefficient | 1.5 | n.a. |
| Maximum pitching moment coefficient | -0.1 | n.a. |
| **Properties of the Pitch Mechanism** | | |
| Maximum pitch speed | 6 | deg./s |

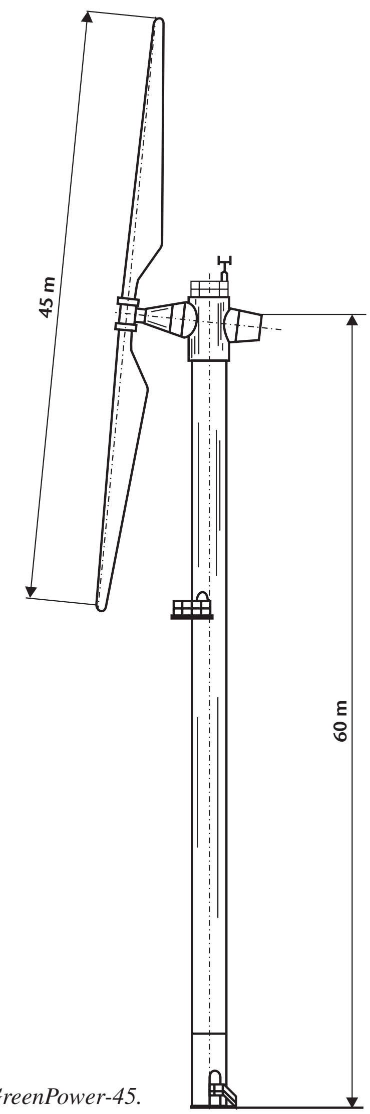


**Figure 4.2** *Overview of GreenPower-45.*

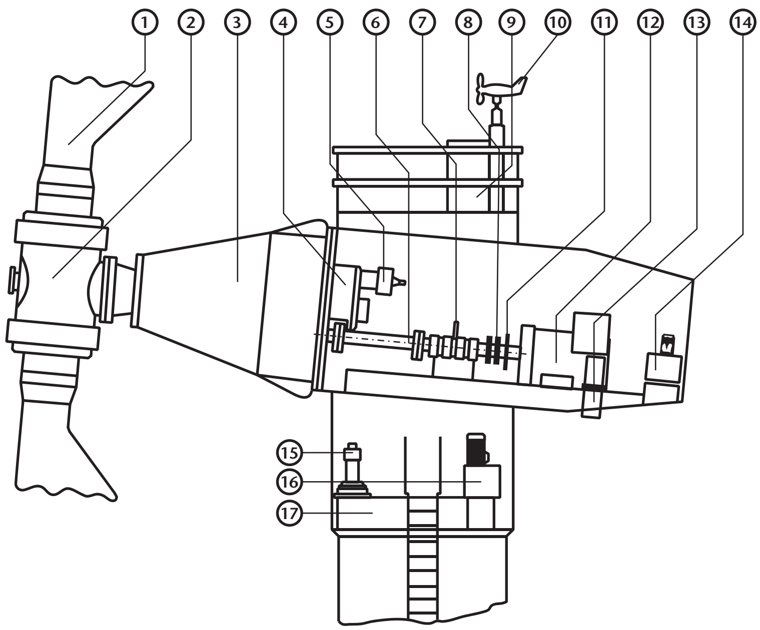


**Figure 4.3** *Technical details of GreenPower-45.*

*1. rotor blade (one)*
*2. hub with pitch adjustment mechanism*
*3. main gear*
*4. pitch adjustment gear*
*5. hydromoter for blade pitch adjustment*
*6a. secondary shaft*
*6b. flexible coupling for secondary shaft (one)*
*7. parking brake*
*8. flexible coupling for generator*
*9. cooling system/unit*
*10a. wind speed and direction sensor*
*10b. wind speed and direction interface unit (to ashore)*
*11. safety coupling*
*12. generator*
*13. suction inlet cooling air generator*
*14. hydraulic pump-set for blade pitch adjustment and parking brake*
*15. yaw-drive*
*16. hydraulic pump-set for yaw system*
*17. yaw-yoke*

The primary information sources for this project were:

- Cost data.
- Energy output figures.
- The logbook.
- Failure reporting sheets.
- Interviews with the responsible actors.

The owner collected operational and failure data in logbooks and on failure reporting sheets since the commissioning of the GreenPower-45 wind farm. The operational experiences from years 1986 up to and including 1993 were compiled. The energy output figures showed to which extent the actual energy output were less than the expected energy output (see below *Operational, Cost and Environmental data of the GreenPower-45 Wind Farm*).

### Impact Assessment

An impact analysis should be made of:

- The energy used for production and installation of the GP-45.
- The energy delivered during the operational lifetime.
- The cost versus environmental impact (Euro/Eco-Indicator Value).

### Improvement Assessment

Firstly, critical considerations should be made about if, how and where wind energy is profitable, according to these aspects. Secondly, design, installation and commissioning reviews should be made to consider if there are opportunities for improvement.

Decisions should be made regarding:

- Options to be used for different ways of producing green energy.
- Different locations of production sites.

## 3 Measurements and Calculations

### Operational, Cost and Environmental Data of the GreenPower-45 Wind Farm

(for demonstration only):

*Project details:*

| | |
|---|---|
| Farm location: | Coastal areas of Northern Europe |
| Farm measurements: | 5 x 5 km (main system) |
| Number of wind turbines: | 25 subsystems |

*Planned lifetime:*

| | |
|---|---|
| Acquisition phase: | 2 years |
| Exploitation phase: | 20 years |
| Phase-out : | 2 years, 2025-2027 |

*Technical data of a GreenPower-45 Wind Turbine.*
The data are collected in Table 4.2.

*Commissioning and decommissioning activities.*
The data are collected in Table 4.3.

**Table 4.2** *Design and Production activities.*

| No. | Installation/components | Cost (Euro) | Production Energy (kWh) | Eco-Indicator Value |
|---|---|---|---|---|
| 0 | Specification and design | 5,000 | 10 | 1 |
| 1 | Rotor blade (one) | 60,000 | 2000 | 9100 |
| 2 | Hub with pitch adjustment mechanism | 40,000 | 8000 | 2150 |
| 3 | Main gear | 90,000 | 5000 | 1500 |
| 4 | Pitch adjustment gear | 20,000 | 1200 | 600 |
| 5 | Hydromoter for blade pitch adjustment | 25,000 | 1500 | 1100 |
| 6a | Secondary shaft | 4,000 | 200 | 100 |
| 6b | Flexible coupling for secondary shaft (one) | 1,000 | 90 | 35 |
| 7 | Parking brake | 10,000 | 1100 | 700 |
| 8 | Flexible coupling for generator | 2,000 | 150 | 40 |
| 9 | Cooling system/unit | 12,000 | 1500 | 800 |
| 10a | Wind speed and direction sensor | 2,000 | 30 | 5 |
| 10b | Wind speed and direction interface unit (remote control) | 3,000 | 40 | 7 |
| 11 | Safety coupling | 17,000 | 1200 | 300 |
| 12 | Generator | 80,000 | 16000 | 4200 |
| 13 | Suction inlet cooling air generator | 1,000 | 70 | 20 |
| 14 | Hydraulic pump-set for blade pitch adj. and parking brake | 40,000 | 2200 | 1500 |
| 15 | Yaw-drive | 25,000 | 1200 | 550 |
| 16 | Hydraulic pump-set for yaw system | 10,000 | 650 | 400 |
| 17 | Yaw-yoke | 15,000 | 900 | 350 |
| 18 | Tower | 150,000 | 24000 | 8500 |
| 19 | Generator housing | 50,000 | 6000 | 1200 |
| 20 | Preservation system | 90,000 | 3000 | 15000 |
| 21 | Condition sensor unit | 20,000 | 300 | 50 |
| 22 | Condition data transmitting unit | 10,000 | 140 | 20 |
| 23 | Monitoring & control station (for 25 wind turbines) | 25,000 | 350 | 60 |
| 24 | Concrete foundation | 5,000 | 20000 | 8000 |

**Project details:**

Farm location: coastal areas of Northern Europe
Farm measurements: 5 x 5 km (main system)
Number of wind turbines: 25 subsystems

**Planned lifetime:**

Acquisition phase: 2 years
Exploitation phase: 20 years
Phase-out: 2 years, 2025-2027

**Table 4.3** *Commissioning and decommissioning activities.*

| No. | Commissioning, Maintenance and Phase Out Activities | Cost (Euro) | Energy used (kWh) | Eco-Indicator Value |
|---|---|---|---|---|
| 1 | Place and put into operation | 15,000 | 50 | 8 |
| 2 | Exceptional transport per trip or per day (100 km average) | 1,200 | 100 | 300 |
| 3 | Crane cost per lift/haul or per day | 1,000 | 50 | 150 |
| 4 | Labor cost per day (average) | 500 | 5 | 1 |
| 5 | Remove the wind turbine | 10,000 | 40 | 6 |
| 6 | Decomm. Rotor blades (two) | 15,000 | 286 | 2275 |
| 7 | Decomm. Hub with pitch adjustment mechanism | 5,000 | 1143 | 538 |
| 8 | Decomm. Main gear | 11,250 | 714 | 375 |
| 9 | Decomm. Pitch adjustment gear | 2,500 | 171 | 150 |
| 10 | Decomm. Hydromoter for blade pitch adjustment | 3,125 | 214 | 275 |
| 11 | Decomm. Secondary shaft | 500 | 29 | 25 |
| 12 | Decomm. Flexible coupling for secondary shaft (one) | 125 | 13 | 9 |
| 13 | Decomm. Parking brake | 1,250 | 157 | 175 |
| 14 | Decomm. Flexible coupling for generator | 250 | 21 | 10 |
| 15 | Decomm. Cooling system/unit | 1,500 | 214 | 200 |
| 16 | Decomm. Wind speed and direction sensor | 250 | 4 | 1 |
| 17 | Decomm. Wind speed and direction interface unit (remote control) | 375 | 6 | 2 |
| 18 | Decomm. Safety coupling | 2,125 | 171 | 75 |
| 19 | Decomm. Generator | 10,000 | 2286 | 1050 |
| 20 | Decomm. Suction inlet cooling air generator | 125 | 10 | 5 |
| 21 | Decomm. Hydraulic pump-set for blade pitch adj. and parking brake | 5,000 | 314 | 375 |
| 22 | Decomm. Yaw-drive | 3,125 | 171 | 138 |
| 23 | Decomm. Hydraulic pump-set for yaw system | 1,250 | 93 | 100 |
| 24 | Decomm. Yaw-yoke | 1,875 | 129 | 88 |
| 25 | Decomm. Tower | 18,750 | 3429 | 2125 |
| 26 | Decomm. Generator housing | 6,250 | 857 | 300 |
| 27 | Decomm. Condition sensor unit | 2,500 | 43 | 13 |
| 28 | Decomm. Condition data transmitting unit | 1,250 | 20 | 5 |
| 29 | Decomm. Monitoring & control station (cost per wind turbine !!) | 125 | 2 | 1 |
| 30 | Decomm. Concrete foundation | 625 | 2857 | 2000 |

## Evaluation of Energy Output

To get a first impression of the overall behaviour of the GreenPower-45 during 1986-1993, the energy output figures were compiled and analysed.

Firstly, the annual output figures are evaluated and the revenue losses estimated. Secondly, the monthly output figures are used to assess the availability and revenues of the turbine.

The energy output figures were compiled to show the extent to which the actual energy output was less than the annual energy output predictions, calculated during the first months of operation, and the theoretically maximum energy output, calculated with the actual measured wind speed. The results are illustrated in Figure 4.4.

In Figure 4.5 the actual energy output figures recorded by the electricity company are compared with the theoretical maximum energy output, calculated by the manufacturer. As can be seen, the actual energy output has stayed far behind by what should be theoretically achievable. Moreover, both the actual energy output and the theoretical maximum are less than the preliminary estimate of 2.3E+6 kWh (2.3 million kWh or 2.3 GWh) per year.

The total financial losses during the eight years of operation are thus about 417,000 Euro, mainly caused by long downtimes and technical troubles. Also the uncertainties in predicting, and calculating the energy output by using the long-term wind speed measurements contribute substantially to the low cost benefit ratio. Furthermore, it should be noted that maintenance and repair costs are not included in this estimate. They have had an additional negative effect on the benefits of the GreenPower-45.

## Calculations

The calculations regarding the environmental impact of the wind turbine should be carried out with support of the Excel sheet provided on CD.

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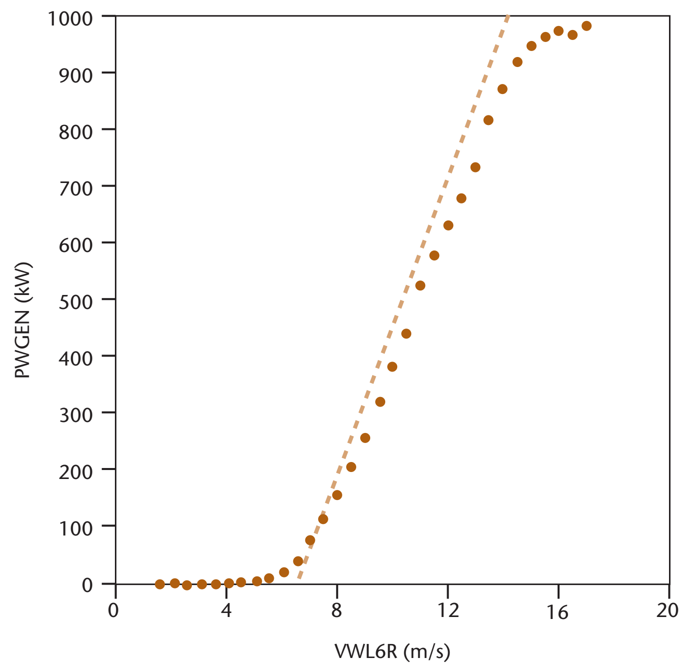


**Figure 4.4** *The theoretical (straight line, dashed) and measured (dots) energy output for the measured wind speed.*

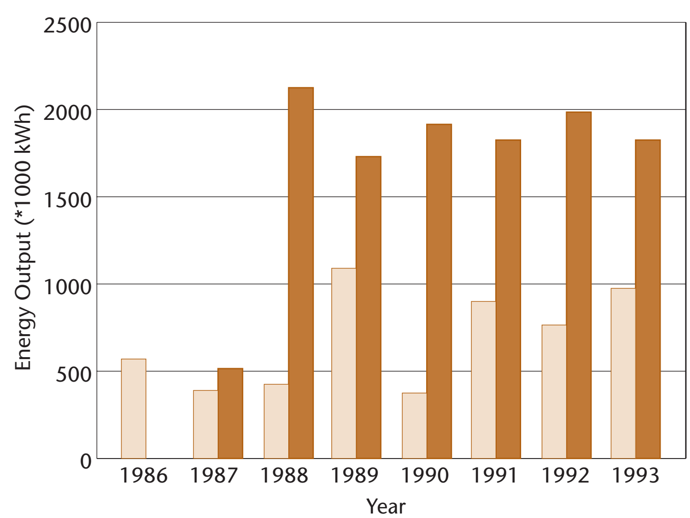


**Figure 4.5** *Measured energy output figures compared with the theoretical maximum energy.*

# Case Studies

B

Case Study 1

**Dutch Flower Fair Association**
The Netherlands



# Ecodesign of Flower Trays – Improving Transport and Management of Flowers, the Netherlands

## 1 Flower Trays

### Flower Fairs in the Netherlands

Every year millions of flower trays (Figure 1.1) in a variety of forms, shapes and sizes are used to transport potted plants from greenhouses to customers, exhibits and retailers in the Netherlands. This has, of course, some environmental impact. The large flower fairs made their own environmental policy plan and appointed responsible individuals to carry out the policy already in the early 1990s. Main topics were energy savings, reduced emissions to water and air, and reduction and re-use of waste.

Expected new legal regulations in addition stimulated the development of a new transport system for potted plants. In the Netherlands there is an on-going discussion on “the agreement on packing” between the government, dealers and industrial chambers on waste management and waste utilisation.

### Millions of Flower Trays

The primary function of plant packing is to facilitate an effective distribution of potted plants from gardeners to a fair, and further on to retail sales. Plant packages may constitute a sale unit containing from 6 up to 20 plants. Besides its distribution function, packages often serve as a means of exhibiting the plants in a shop.

Nearly 46% of potted plants were transported to the flower fairs in multi-use packing (Table 1.1, data from 1990). The amount reached up to 20 million plants a year. The packing was the property of the fair, which provided discounts for retailers and salesmen for operating and stock costs as well as the rent fee. The packing, made from polyethylene, was returned to the fair. There were many different types of packing as a result of the flower pots’ variety – from 5.5 cm up to 15 cm in girth (sometimes even more) and of different angle – from 5 to 8 degrees.

The rest of the potted plants (54%) were transported in different single-use packing. Gardeners purchased this packing either at the fair or directly from a producer. The most often used packing was that of polystyrene (20 million pieces a year). Apart from this, some plants were transported in hermetic boxes of polystyrene and in thick cardboard packing with a synthetic coating. Every year ca. 13 million ruffled cardboard boxes were used to transport plants of substantial size. This packing was recycled and did not constitute a serious threat to the environment.

### The Ecodesign Project

The development and implementation of a new plant transport system for potted plants was initiated already in 1990 by the Associated Flower Fair in Aalsmeer (VBA). The project was co-ordinated by the Dutch Flower Fair Association, while the responsibility for project management stayed with the TNO Product Centre. A team of designers and constructors made the initial problem analysis and the conceptual design and developed the solutions. Dynoplast, a company operating in the waste and synthetic material recycling field, continued the analysis and became responsible for the final product development. CML supported the project.

### The First Ideas

The initial ecodesign brainstorming sessions came up with two principles for new packing for potted flowers. These served as starting points for the project development. The first concept was a multi-use packing with a single-use, coated tray containing many outlets. These outlets may come in various sizes depending on flowerpot types. The advantage of the single-use tray is that it may have any text (commercial) printed on it. The second concept was a multi-use packing with a reticular pattern of edged outlets on which flowerpots could be placed. Here flowerpots of various sizes may be transported in a single packing. This means, however, that all flowerpots had to be adjusted or else they would be difficult to place in the packing.

The ecodesign project team began by gathering data and comparing ecological features of the single and multi-use packing. The consequences of environmental legislation with regard to plant packing were presented in graphics to make it easier to choose between the two concepts. The figures show two possible designs at the beginning of the project. The first one (Figure 1.2) was a two-layer tray with a single-use top and a multi-use bottom. The second one (Figure 1.3) was a total multi-use tray with universal raster to fix the different type of pots.

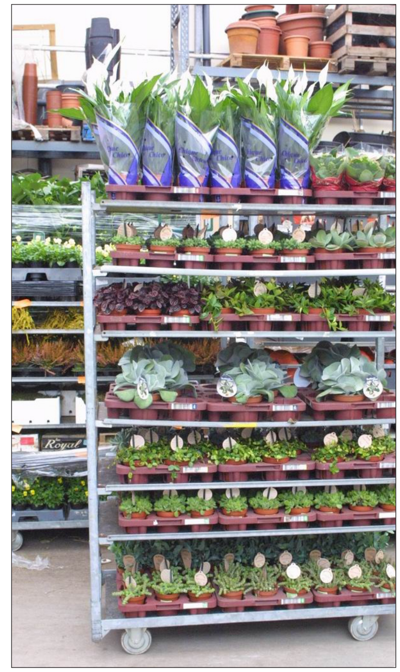

**Figure 1.1** *Flower trays at a flower fair.*

**Table 1.1** *The use of packing trays (Dutch Flower fairs, 1990).*

| Transport | % | Tray weight | Pieces/Year |
|---|---|---|---|
| Multi-use trays | 46 | 800 g | 20,000,000 |
| Single-use trays: | | | |
| – Polystyrene foam | 46 | 80 g | 20,000,000 |
| – Polystyrene vacuum shaped | 6 | 140 g | 2,500,000 |
| – Massive cardboard | 2 | 315 g | 800,000 |
| Total | 100 | | 43,300,000 |

## 2 Analysing the Environmental Impact of Flower Trays

### Multi or Single use Trays

Increased sensitivity to the issue of environmental protection and to the issue of waste management in particular, has made the market negative to single-use packing. Legislation in Germany and the Dutch agreement on packing consider it crucial to drastically reduce packing waste. Single-use packing will be collected and recycled.

The environmental analysis supported effective multi-use instead of single-use packing. The former may be used nearly 90 times, which results in substantial savings on resources and waste. This benefit is considerably greater than that generated from increased transport weight of multi-use packing and return transport with empty plant packing.

**Table 1.2** *Results of the ecodesign environmental analysis.*

| Tray (Product) | Energy use (GJ) | PAU (1000m³) | PWU (1000m³) | AU (m²/year) | Solid waste (kg) |
|---|---|---|---|---|---|
| Single use Polystyrene foam | 7.4 | 200 | 130 | 480 | 50 |
| Single use Polystyrene vacuum form (a) | 12.7 | 300 | 230 | 720 | 84 |
| Single use Solid Cardboard (b) | 3.2 | 450 | 34 | 1200 | 240 |
| Existing multi-use | 0.8 | 27.8 | 7.3 | 65 | 4.8 |
| New single- and multi-use (b) | 1.9 | 200 | 18 | 533 | 102 |
| New multi-use | 0.7 | 26.3 | 6.0 | 62 | 4.0 |

Note:
(a) By using recycled material the environmental impact can be decreased significantly.
(b) Recycling of cardboard is not taken into account.

In the project this analysis was thoroughly checked. Three types of single-use packing, one multi-use packing and two new multi-use packings were compared in terms of environmental impact. The case study included assessment of the environmental impact of individual production and recycling phases. The following parameters were used:

- Energy use (Giga Joule)
- Emission in the atmosphere (in $m^3$ of polluted air; in Polluted Air Units: PAU)
- Emission in the water (in $m^3$ of polluted water, in Polluted Water Units: PWU)
- Soil acidity (in $m^2$ of soil acidity, in Acidity Units: AU)
- Solid waste (in kilogram).

The results are given in Table 1.2.

## Shipment

As regards the shipment of potted plants, the weight of packing is not the most important factor since this is mainly capacity transport. The packing weight constitutes ca. 1% of the maximum load, and according to the TNO Institute it amounts to 0.2% of the total fuel consumption during road transport. Still, the limitation of packing weight is a final aim from the point of view of material savings.

Single- and multi-use packings differ significantly, especially as the latter undergoes return shipment. In practice, it is unlikely for the return shipment to cause any extra burden on the environment. The companies which transport plants may ship empty packing along with empty trailers. Therefore, there is no need to organise additional shipments. In the Netherlands, and certainly in Germany, single-use packing will have to be transported back. Therefore the expected difference in return shipment of single- and multi-use packing is rather small.

A special parameter was added to facilitate the comparison of environmental impact of shipping of single- and multi-use packing: “material required to ship ten thousand potted plants”.

## Washing

The other difference between single- and multi-use packing lies in the need to wash or rinse multi-use packing. At the time there was no such practice, as only flower containers were cleaned. As data presented by the Associated Flower Fair in Aalsmeer (VBA) on cleaning flower containers is combined with data on plant packing, a complete picture of the environmental consequences of rinsing will be achieved. Flower containers may be rinsed with half the energy and compressed water without salt solution, if the hygiene demand is less strict. Then the energy use constitutes the main impact on the environment.

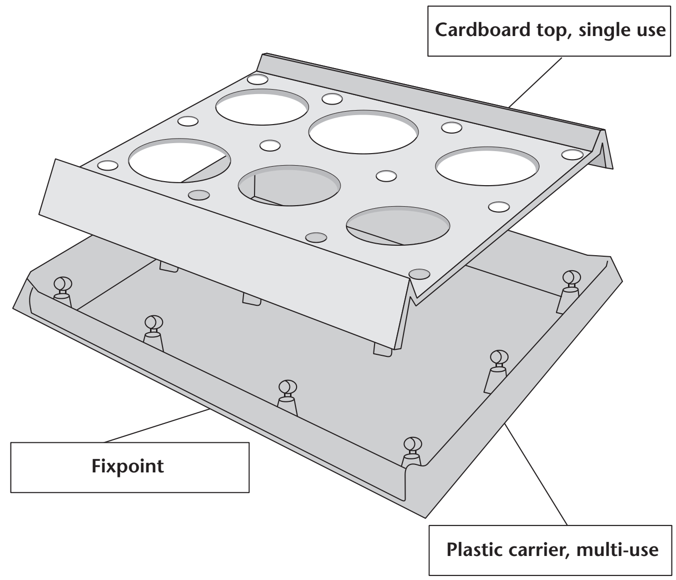


**Figure 1.2** *A two-layer tray with single-use top and a multi-use bottom.*

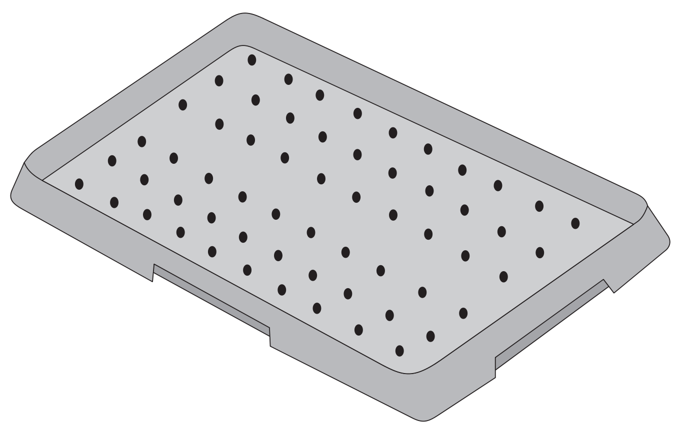

**Figure 1.3** *Multi-use tray with universal raster to fix the different type of pots.*

The environmental analysis to reflect this included data on the “environmental impact of washing ten thousand plant packings”.

## Conclusions Drawn from the Analysis of Environmental Impact

The main conclusions from the environmental analysis were:

- In all areas examined the burden on the environment from multi-use packing is substantially lower than that of single-use packing.
- Shipment (return) and possible washing of packing do not produce any significant effects even in the case of long

transport (from the south of Germany) and of rinsing the packing every time it has been used.
- Multi-use packing with a single-use, replaceable tray has a substantially higher influence on the environment than the total influence of all multi-use packing as a whole. Yet it is less severe than that of all packing examined.
- Few multi-use packings exert a lesser burden on the environment than present packing thanks to their lower weight and better load dimensions.

New proposed new module dimensions (28 x 40 cm and 56 x 40 cm) constitute an acceptable compromise between Dutch fair trailers and Danish trailers in terms of load dimensions.

New multi-use packing is to serve all sizes and types of flowerpots and plants. On the other hand, some limit has to be imposed on the number of various types of packing (reticular pattern) since this would result in significant logistical savings.

## 3 The Ecodesign Project

### The Design Process

The ecodesign management began when one solution had to be chosen from two different concepts. One component in this process is to carry out an environmental analysis that compares the new concepts with existing and newly developed packing.

Fairs responded enthusiastically to twofold packing because it provides many logistic solutions. However, from the environmental point of view multi-use packing will be more suitable than the twofold one. Still, this is not so sure since multi-use packing with replaceable trays may serve a major part of the market due to the effectiveness of this solution. This might benefit the environment because single-use packing will no longer be necessary.

The team decided to work on both concepts.

The design process management focuses mainly on minimising the use of material both in the process of multi-use packing and twofold packing production, and particularly on the manufacturing of the replaceable single-use tray.

### Priorities

The following priorities were made to assess the different individual solutions for multi-use packing:

- Serving the whole market. The packing should be suitable for all sizes and types of flowerpots used. A general concept for the product design was asked for.
- Optimum load degree. As many flowerpots as possible should fit in one packing, to limit transports and handling. For multi-use packing the new module with dimensions 56 x 40 cm provides optimum use of space.
- Savings on weight and material. The limitation of packing weight contributes (slightly) to decrease fuel consumption during shipment, and limitation of material used.
- Material used. The material for multi-use packing must have a potential for recycling and further use after recovery. Minimal material use, minimal difficulties during manufacturing, and possibility for further use of recycled materials are equally important.

The further development of the project was based on the agreement on packing, which required a 10% decrease in the weight base of packing waste for the year 2000. In order to achieve this goal, the share of multi-use packing would have to increase from 46% (1990) to 80-85% in 2000. If a single-use packing were still used, in the future it would have to be collected and recycled in order to meet the minimum requirement of 60% of packing waste recycling. This would require a switch to packing made of materials that can be easily recycled.

Which material is the most suitable for the replaceable tray manufacturing? Data collected by the project co-ordinator indicate that there are three possibilities: thick cardboard, ruffled cardboard and paper pulp. Due to its high dampness resistance and a lower price, the thick cardboard (without synthetic coating) is considered to be the best alternative solution in terms of a material for a replaceable, single-use tray. The fair representatives used models representing the two concepts of the product to reach an agreement with dealers and gardeners.

### Agreeing with Stakeholders

Deciding on a new form of the packing is a very complicated process in such a complex structure as that of flower fairs. The whole chain of representatives (gardeners, fairs, transport companies, dealers at home and abroad) has to be convinced that it is necessary to introduce changes.

The packing has to meet logistics requirements, and this in turn implies adjustment and high investment costs. The ecodesign team produced an intermediate report to support the process of deciding on a particular solution. The report described the consequences of new legislation in Germany and the Dutch agreement on packing with reference to plant packing. In the whole production process the ecodesign team carried out a thorough analysis in order to present the advantages that the use of new packing brings to the environment. The fairs passed on further prerogatives to the company involved in the synthetic material recycling. Due to financial problems there was no support for the ecodesign project of a one-fold single-use tray.

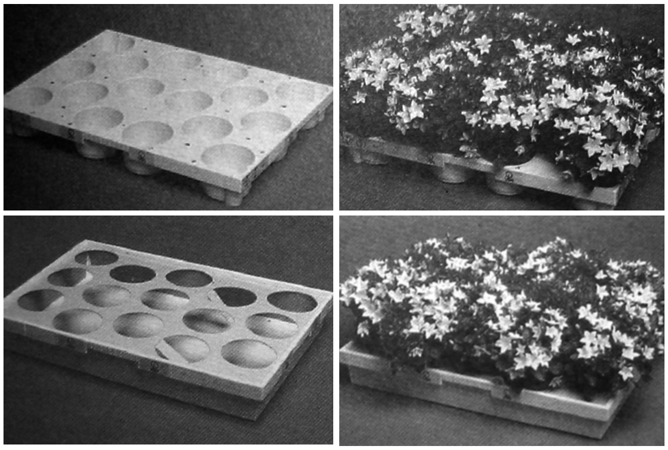

**Figure 1.4 Intermediate results of plant tray ecodesign.**
*Top: Intermediate result – model of multi-use tray.*
*Bottom: Intermediate result –model of single-use tray.*

## 4 The Solutions – Nine Different Products

### The Final Solution

The project's final results consisted of a series of nine different solutions for multi-use plant packing with variable outlet patterns. Three small containers (28 x 40 cm) are designed for smaller plants, and six big packings (56 x 40 cm) for bigger ones. Despite various outlet patterns, these containers may be put one on another. This series enables the shipment of all of the most common potted plants. Two open containers of dimensions 28 x 40 cm and 56 x 40 cm allow placement of replaceable single-use trays inside them. Thanks to this solution other plants (blooming or exceptionally gentle ones) of rare size or in flowerpots of irregular dimensions may be transported easily. Packing is moulded from HDPE (high density polyethylene). Bigger packing (56 x 40 cm) weighed ca. 650 grams. Cardboard replaceable trays for twofold packing are made of thick cardboard without synthetic coating. The material used came from recycled paper.

The packing was developed thanks to a concentrated effort of joint Dutch fair organisations and, therefore, it became a regular product in the Netherlands. If multi-use packing proves its function in practice, the use of single-use packing at flower and plant fairs in Holland may be reduced to a minimum in the long run.

Plant packing waste constitutes the main source of waste at the fairs. This project provides an effective solution to this problem. The project became part of a complete environmental company policy.

### The Environmental Advantages

Product quality improvement. The new module size of the plant packing (56 x 40 cm) and the maximum dislocation of flowerpots determine the optimum load level. This contributes to distribution efficiency, which indicates that the new multi-use packing may compete more effectively with single-use packing. Different packing (with various outlet patterns) may be placed one on another, which makes the return shipment more efficient. Stylish design of the packing makes it applicable for plant exposition in a store.

Savings on material used and cycle completion. The most distinct ecological advantage from the development of multi-use packing is that of providing service for a greater portion of the market. If the market shares of multi-use packing increases from 45% up to 85%, the savings on material used, and thus the prevention of waste build-up, will increase to over 1,000 tonnes a year. The packing weight has been reduced from 800 to 650 grams, thanks to which 20% less material is used in the production process. Research is being carried out to increase the percentage of recycled material used for packing production.

### Efficiency and Power Savings

The energy required in an individual multi-use packing production cycle is 90% lower than that required to produce single-use packing (from polystyrene). Of course, some extra energy is used due to a heavier shipment, yet it is a negligible amount.

Reduction of toxic emissions. The majority of toxic emissions occur during the production of packing materials. Since less material is used in the multi-use packing life cycle then in the single-use one, the emission of toxic substances has been reduced considerably as well. The most significant emissions into the atmosphere and water have been reduced by 90%.

Economic profit. In order to provide financing for production cost and exploitation of multi-use packing, the fairs settled on the following rent fee: 0.10 Euro for gardeners and 0.10 Euro for salesmen. According to the fairs this fee of 0.25 for packing rental in a single cycle is enough to cover exploitation costs. Total costs for salesmen amount to 0.25 Euro, and return shipment costs. Return shipment of packing does not imply additional costs for salesmen since fair lorry fees are collected in advance. Single-use packing costs amount up to 0.40 Euro a piece. Waste recycling does not involve additional costs because used packing undergoes a regular waste cycle or is deposited directly at manufacturers for reuse. Based on this analysis the conclusion may be drawn that both the gardeners and the salesmen obtain the same economic advantage by using multi-use packing.

Product changes in progress. The packing producer is still examining the possibility of adopting recycled materials in the

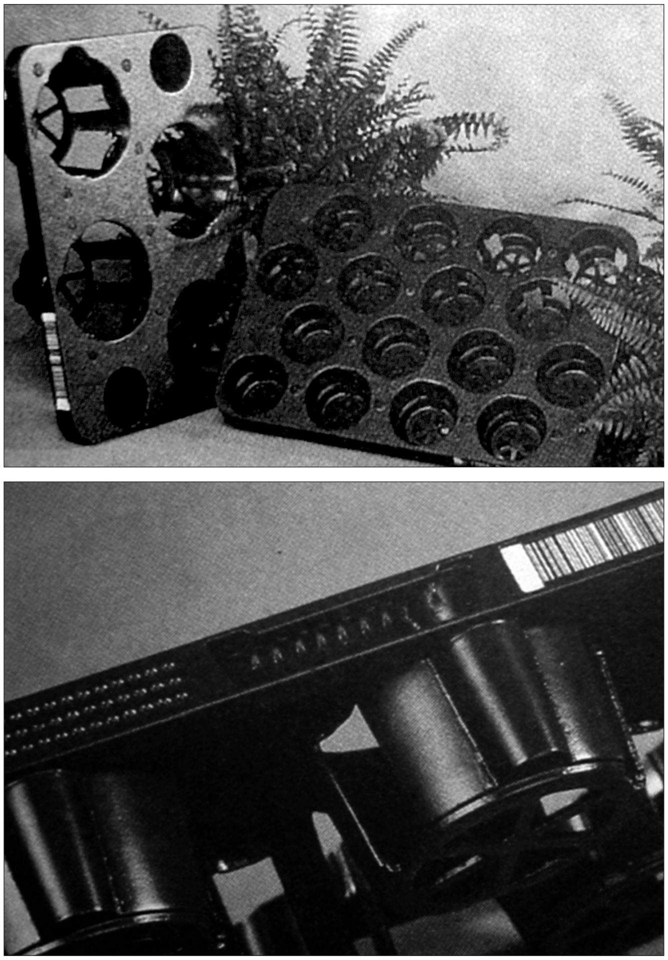

**Figure 1.5** *Final product of plant tray ecodesign.*

new packing production process. An argument against using recycled material is that of its inferior quality, which implies the necessity to produce thicker walls for packing. However, this does not need to be an obstacle.

### Final Comments

The ecodesign project proved that it is possible to improve the product. As an indirect result of this, the fairs started negotiations with packing producers and suppliers of other containers (plastics and flowerpots) on the product quality improvement.

The fairs have expressed a positive opinion on the ecodesign project. It has supported them in making a decision on various concepts and individual solutions. Arguments have been put forward to convince other players of the supply chain: gardeners, distributors and salesmen. The concept to convince these groups was developed in a separate project.

The most significant environmental advantage of using multi-use packing was that of operating on a greater portion of the market. The new module dimensions (56 x 40 cm and 28 x 40 cm) and a major degree of capacity-load of Dutch fair lorries and of Danish Euro palette type trailers enabled the use of packing both in Holland and for export. Due to this, multi-use packing became more attractive to use for export as compared with plant packing then available on the market. The new packing was prepared for the toughest legislation as regards potted plant shipment within the country and abroad, without compromising plant distribution efficiency.

Ecologically oriented product developments may turn the threats posed by legislation on packing and possible huge increase of costs into an opportunity. The new, multi-use plant packing is environmentally friendly, primarily due to materials used and waste reduction. The effective system of multi-use packing enables all groups in the chain to save costs in the long run.

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## Reference

Eco-design: acht voorbeelden van milieugerichte productontwikkeling (1994). Productiecentrum TNO/NOTA: Delft, ISBN 90 346 290 31 (in Dutch).

**Case Study 2** | **The Ahrend Company**
The Netherlands

# The Office Chair – A Ecodesign Project at Ahrend, the Netherlands

## 1 The Chair Project

### The Ahrend 220 Chair Project

The project called Ahrend 220 was developed by a team from marketing, research, design & development, and tool and model design departments. The goal was to replace a common office chair with a new and better one. The most important requirements for the new chair were:

- The purchase price had to be low; it is a critical element.
- The product had to follow Dutch environmental standards.
- The life cycle of the product should be at least 6 years.
- The chair should be possible to re-cover with cloth.
- Product recycling should be taken into consideration.
- Return of old pieces of the product is not taken into consideration.

In practice the project team at ecodesign co-operates with the research and design department. The task teams focus on the process improvement while the ecodesign team concentrates on the product improvement. During the project development it appeared that it is not always possible to mark a division between the process and the product, e.g. with regard to forces exerted on the environment by the RIM method. Already before the company had decided on which materials to use.

### Product Analysis

The first concept for the new product *Ahrend 220* consisted of ten pieces. Every piece had different composition, colour, weight, joints, finish and producer. Two categories of indicators were set to assess the environmental impact of the new chair:

*The weight proportion* of individual pieces. This is the simplest indicator of environmental influence of individual pieces, less weight less influence.

The harmful *effect of material on the environment*. This was expressed as control points in an ecological matrix. The ecological matrix was defined for each phase of the product's life cycle. Criteria were defined for raw material (availability, energy capacity, durability), emissions (air, water, soil) and for solid waste (decomposition, recycling, harmful effect). Then, the harmful effects of various materials on the environment were calculated using three different LCA methods.

The first analyses looked at three crucial parts of the chair.

*Cross*. The cross was decisive for determining the weight of the chair. Environmental improvement of the cross may result in substantial environmental advantages. The choice of material was nylon strengthened with glass fibre (polyamide).

*Seat and support.* In the seat and support, common parts (material, horizontal surface and foam) were firmly joined together. The choice of polyurethane foam for the seat was controversial. It is likely that polyurethane exerts a harmful effect on the environment during the production phase, and when it is hardened thermally. In spite of this, the company was not prepared to consider a different material. It had just invested in a new production method, and any changes in the process would have consequences for the production. Later work, however, did not find a better alternative for the seat, as shown by remodelling and an economic analysis.

**The Ahrend Company**

The Ahrend Company, providing furniture and furnishing advice, office products and reprographic services, was founded in the Netherlands in 1896.

Ahrend Office Furnishing intends to combine service and furniture design with functionality, ergonomics and quality. Protection of the environment has a high priority, alongside with other company objectives. Ahrend's vision is a sustainable future, with a balanced view on social, economic and ecological values. The product policy is developed in a research project with Stichting Natuur en Milieu (Dutch Foundation for Nature and the Environment). The policy, includes design for recycling, and minimising the overall "environmental score" of the products.

Ahrend has two production plants. The Sint-Oedenrode plant mainly produces steel office furniture, the Zwanenburg plant mainly office chairs, school furniture and partition walls. Both production plants have been active to reduce the environmental load they give rise to, and have introduced environmental management systems and are ISO 14001 certified. They both publish environmental reports annually. APS is registered by the Foundation for Coordination of the Certification of EMS as a participant in the European Eco Management and Audit Scheme, EMAS. Environmentally oriented product development or "ecodesign" has been used for several years in both plants to monitor and, where possible, reduce the environmental load caused by the products.

Further information on the environmental work of Ahrend can be found on their website:

*http://www.ahrend.com*

The Ahrend 220 chair meets strict requirements regarding environmental impact and recyclability. The chair is available in a range of designs for office, visitors, conference and work stations. It was available on the market in 1994 and is still sold. The designer is Henk Verkerke.

*http://www.ahrend.com/smartsite.dws?id=3319*

*Construction***.** In the construction part it was essential to find ways to easily disassemble the main parts, such as the seat and the support. This turned out to be difficult and became a threat to the entire project.

## 2 Formulating the Alternatives

### The Process of Finding a New Chair Concept

The next phase was to define priorities for building the chair. Each of the three parts of the chair was examined. The process started with searching for alternatives. These were included into a scheme (Figure 2.2) and choices between these were made after each of three cycles. Figure 2.2 illustrates the process for the cross foot.

The result of the process, called concept 220, was then examined using the ecological analysis as described above. The analysis indicated that there were certain ecological concerns which could not be solved by means of adjustments of the construction.

### Ecological Analysis of the Chair Concept

The most important ecological points were the following:

- *Some materials* for the parts may make disassembly and recycling difficult.
- *Composites* (nylon, glass) and *synthetic fibres* mixtures may make recycling difficult.
- *Nylon* may require a great deal of energy in production.
- *Polyurethane*, may give rise to toxic emissions (e.g. isocyanite) during production, and formation of foam (CFK). There were limited possibilities of finding substitutes.
- V*arious coverings* may contain toxic pigments (heavy metals – iron, copper, etc.).
- *Chrome application* may give rise to toxic emissions.

The use of materials, construction, and the most important ecological concerns of the chair concept are summarised in Table 2.1.

### Creating an Innovative Space

Next a so-called *innovative space* was created to further develop the concept. The starting points were the limitations set by the company and the results from the ecological matrix.

The company's limitations of the product development were concerned with material use, changes in the construction and process of production. One consequence of these limitations was that material use was limited by the introduction of round parts and thinner walls, that is, a dematerialisation.

The environmental analysis in the ecological matrix described the life cycle of steel as compared to the life cycle of nylon, the life cycle of glass fibres and of polyurethane as compared to coconut fibres with original latex. In this phase the following alternatives were finally suggested:

- An exchange of synthetic fibres for transformed aluminium or steel.
- A reduction of the variety of synthetic fibres used in the chair concept and a construction enabling the disassembly of parts made from synthetic fibres.
- Adjustment of a brand new supports concepts using the construction with no horizontal surface where the material is stretched in a solid frame.
- Limitations in colour and chrome application to reduce the emission of toxic substances.

An expert on environmental protection, who examined the environment impact by toxic pigments, advised the use of the pigment of chink black. The emissions in this way stayed reasonably low, due to the fact that relatively little pigment would be used in the production of the chair.

## Experiences from the Concept Development phase – Gathering Information

A very substantial amount of information was needed in the process of setting priorities and developing a new concept. The data required were found in research institutions, in companies and as a result of discussions with experts. Here a balance had

**Figure 2.1** *Original model of the office chair (Ahrend the Optis).*

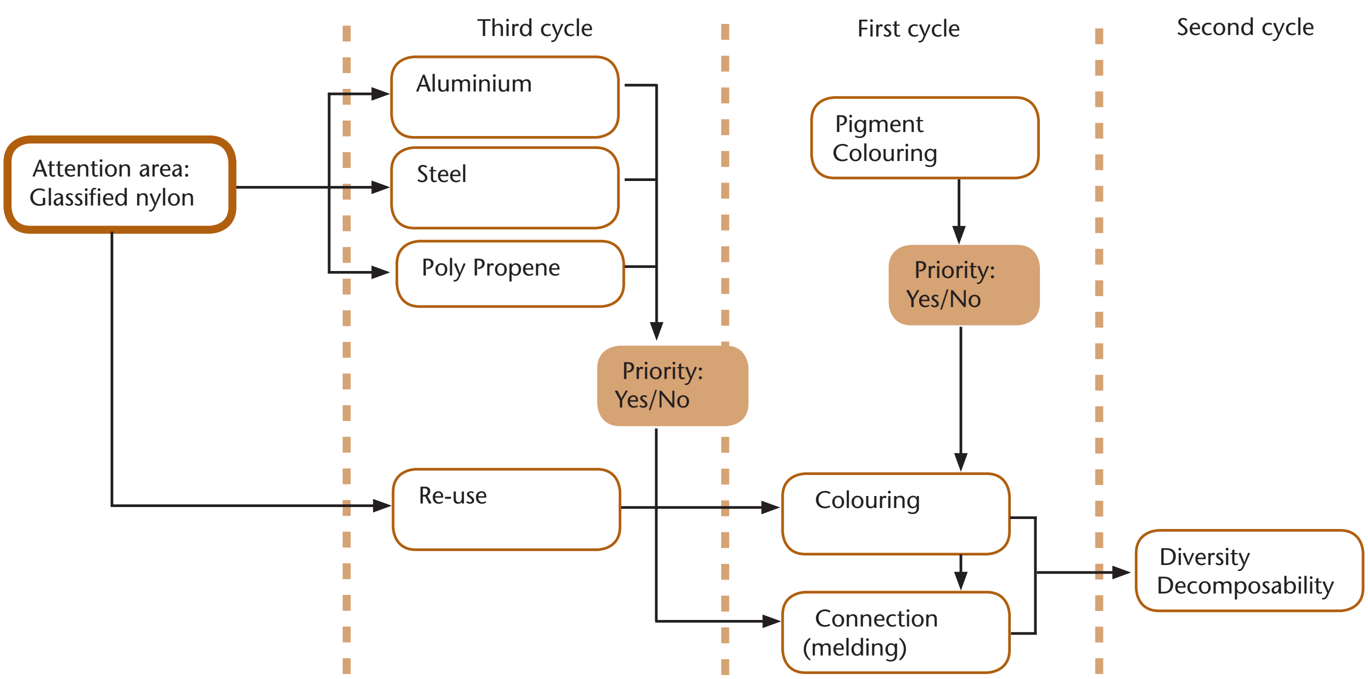


**Figure 2.2** *Example of priorities in searching for alternatives of the "crossfoot".*

**Table 2.1** *Use of materials, construction and environmental attention points.*

| Part | Material | Construction | Environmental attention point |
|---|---|---|---|
| 1. Wheels (5x) | | | |
| Purchase<br>Steel 180 gram<br>Nylon 355 gram | Nylon 30% glass fibre | Axis: insert<br>Steel axis wheel-crossfoot dismountable | Nylon: energy, re-use<br>Steel: re-use connections: Dismountable, re-use |
| 2. Crossfoot (1x) | | | |
| Boarding-out<br>Nylon 1250 gram<br>(Aluminium 2200 gr)<br>(Steel 3600 gr) | Nylon 30% glass fibre<br>Colour: grey, red, green and blue<br>Chromium-plated plating: emissions<br>Coatings: pigments | Footcovers: ABS (against wear) | Nylon: re-use plastics: re-use |
| 3. Suspension column (1x) | | | |
| Purchase<br>Oil fillings<br>762 gram | Steel<br>Rubber seals<br>Painting/coating<br>Coating: pigments | | Steel: re-use |
| 4. Ferrule (1x) | | | |
| Boarding-out | Polypropylene (PP)<br>Pigment on PP<br>Colour: grey or others | Fixed mounted<br>Dismountable | |
| 5. Carrier (1x) | | | |
| Control and cables<br>Purchase rubber<br>1600 gram | Steel<br>PP<br>Colour: grey (powder) pigments | Multi element assembled | Re-use, dismountable |
| 6. Seat and support | | | |
| Partly purchased | | | |
| A: carrier | Abs/pc, wood (1880 gr) or steel (1660 gr) | RIM process | Plastics: dismounting, re-use |
| B: filling | PUR-foam (1074 gr) | | PUR: emissions, re-use |
| C: cover | Nylon (PA: 600 gr) or polyester (PETP: 574 gr) | | |
| 7. Side parts | | | |
| Seat and support<br>Board-out | Nylon 30% glass fibre<br>PP protection covers<br>Colouring<br>Coating: pigments | Fixed to carrier<br>Fixed to side parts | Nylon: re-use<br>Dismounting, re-use |
| 8. Arm supports (2x) | | | |
| Board-out<br>600 gram | Nylon | Double component technique | Connections: dismounting |
| 9. Support cover (1x) | | | |
| Board-out<br>400 gram | Polypropylene<br>Colour: black | Fixed | Dismountable |
| 10. Other parts | | | |
| Packaging, glue, paint, seals, fillings<br>965 gram | PE isocyanate, pigment, rubber, steel, mineral oil | Several types | Pigments Plating (Chromium) |

to be struck between having enough data to achieve a reliable result, and the time used for this work. A complete quantitative analysis of all alternatives was not possible. The experience of the company was that it is better to point out the main obstacles and potential solutions rather than to give exact figures while setting priorities.

An important issue while setting priorities and making a choice for the Ahrend 220 model was the ecological information. The majority of ecological data came from the supply chains at Ahrend (suppliers and receivers). It was considered a far better solution to gather information from the market than to use written sources and consult independent experts. One problem that remained, however, was the issue of the durability of recycled nylon and glass composites, which had being questioned by specialists. The only guarantee for a high quality recyclable nylon may be a signed declaration of the supplier of this material. Similar problems accompany the process of polyurethane recycling and of dyeing of individual chair parts.

## 3 The Design Process

### Development

The development process was split into four phases.

- *The design phase (ca 6 months).* In this phase the concept and material were decided on. As a result a concept was created which described all possible ways of unfolding the chair and its forms. Space models were used for the purpose. The ecodesign project began with choosing (partially) the material and the complete construction of the chair.
- *The construction phase (ca 6 months).* In this phase details were analysed, and a prototype created in due course. The ecodesign team participated only in the beginning of the construction phase. In the end the concept and material chosen was evaluated by the ecodesign team.
- *The tools-used preparation phase (ca. 12 months).* The conditions for beginning a new series of production were set. Tools and matrices were defined. The ecodesign team did not participate in this phase.
- *Zero series.* The zero series began the test production of the new chair. Phase 4b, that is the product introduction onto the market, began in the spring of 1994.

The ecodesign team did not have any influence on the traditional design process as such. However, the design phase lasted 2 months longer due to the ecodesign. The ecodesign was only allowed to go into aspects of the construction of the Ahrend 220 chair, which did not shorten the following construction phase. The delay of the process was a direct result of the time necessary to create the so-called "innovative space" for alternative choices on the material and the construction.

The search for alternatives consisted of a set of preparations, which include actions regarding material selection, aspects of specification for suppliers, construction and organisation. Individual courses of action were decided on in terms of short- or long-term applications, and whether it would occur in the production process of the Ahrend 220 office chair.

### Project Results

The concept from the beginning of the ecodesign project was used as a reference product, to which the final product was compared after the intervention of ecodesign. This comparison (Table 2.2) described all changes introduced for the individual parts of the chair.

**Table 2.2** *Changes introduced for individual part of the chair.*

| Part | Material changes | Construction modifications | Other modifications |
|---|---|---|---|
| 1. Wheels (5x) | no | axis-wheels separate dismountable | re-useable |
| 2. Crossfoot | colour: black; no chromium | foot covers: nylon | re-useable |
| 3. Suspension column | only powder coating | | re-useable |
| 4. Ferrule | colour: black | separate | dismountable |
| 5. Carrier | only use of PP | simplified construction | dismountable |
| 6. Seat + support | use of PP | colouring | |
| 7. Side parts | only nylon/glass fibre | coating: black | re-use |
| 8. Arm supports | | hollow spaces | dismountable |
| 9. Support cover | strive to PP | | |
| 10. others | | | |

## Environmental Benefits

The most important *qualitative* results for the environment were:

- Reduction of the waste due to the nylon recycling and increased recycling of steel.
- Reduction of resource use due to use of recycled polypropylene.
- Decrease of energy use due to use of recycled nylon.
- Decrease of easily dissolved substances.

The suppliers were able to substantially reduce the use of heavy metals in pigments below the level of chemical waste, 50 ppm.

The Ahrend company wanted to withdraw certain substances from being used and recycled. After the ecodesign was finished, the company changed the chair production process so as to disassemble the seat, foam and covering.

The *quantitative* results could only be properly estimated by an LCA of the chair, which was not done due to funds and time shortage. An approximate result is however presented in Table 2.3. The analysis included the main parts but not supportive materials. Yet the calculations account for the limitation and recycling.

This type of quantitative evaluation is not as precise as might be expected. An expert evaluation estimated that the emission of greenhouse gases had decreased by 33%, and the emissions of acidifying substances had been reduced by 20%. The ecological costs for the complete production chain had decreased from about 5.6 to 2.5 Euro for a single office chair, as calculated on the basis of marketing rules in the long run.

**Table 2.3** *Reduction in of material and energy flow and emissions (concept and ecodesign).*

| Material | Concept | Ecodesign |
|---|---|---|
| Steel | 2851 | 2851 |
| Nylon/glass | 3606 | 721 |
| PUR | 1074 | 1074 |
| PE,pack | 421 | 421 |
| Chrome | 57 | 0 |
| Pigment (by re-use the same amount of pigment will be added) | 104 | 0/104 |
| **Energy** | **Concept** | **Ecodesign** |
| GJ (fuel) | 0.46 | 0.26 |
| GJ (elec) | 0.02 | 0.01 |
| **Emission (air)** | **Concept (gr)** | **Ecodesign, reduction** |
| $NO_x$ | 11.40 | 37% |
| $SO_x$ | 11.10 | 30% |
| Phenol | 0.11 | 80% |
| Fluorines | 8.60 | 79% |
| $CH_x$ | 0.40 | 80% |
| **Emission (water)** | **Concept (gr)** | **Ecodesign, reduction** |
| COD | 783.00 | 59% |
| Chrome | 0.02 | 16% |

# 4 Consequences for the Company

## General Consequences of Ecodesign Project

The ecodesign project influenced certain processes within the Ahrend company:

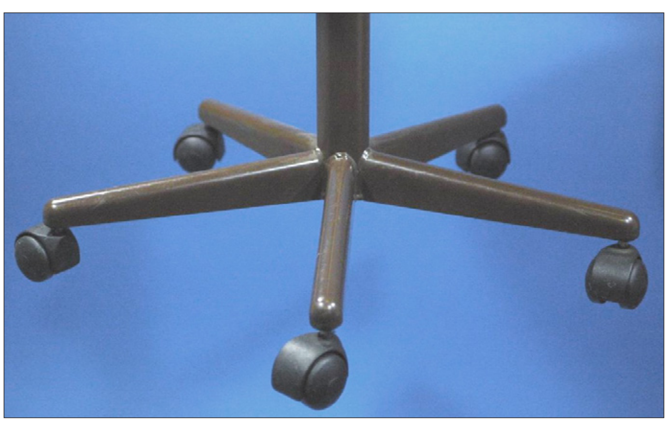

**Figure 2.3** *Different points to discuss.*

- The implementation of ecological aspects in product development has accelerated.
- The check list for the development process includes starting points for the environment.
- A demand for training sessions and aids for designers.
- The supply unit has began negotiations with suppliers.
- A regular check on ecological aspects of other products manufactured by the company.

## Final Evaluation

The project met the set conceptual demands. The new Ahrend 220 chair did not allow for the introduction of extensive changes. This was particularly obvious with regard to the seat. The initially set production cost did not allow the choice of other materials.

The advantage achieved with regard to the environment was in the end a result of the suppliers' agreement to deliver parts, and of the Ahrend's agreement to develop projects for

**Figure 2.4** *The new ecodesign model of office chair Ahrend 220.*

disassembly and recycling. In practice, the advantage to the environment will be achieved when the chairs are delivered. Some changes have been introduced in the construction and coverings.

The company evaluated the co-operation with the ecodesign team favourably. It contributed to the increased knowledge of environmental aspects in the company making future ecological projects easier. The co-operation within the ecodesign team was considered helpful. The project management and ecological analysis supplemented each other.

Ecological aspects have received a more important position in the strategy of the company. In the initial requirements regarding the Ahrend 220 chair only a few ecological issues were included. However, the company did not know how to deal with the issues concerning environmental protection. The ecodesign project made up for this lack of experience in management of ecological issues. The company has taken advantage of the knowledge acquired in subsequent projects and introduced some strict and binding rules regarding project management.

## Contacts

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## Reference

Eco-design: acht voorbeelden van milieugerichte productontwikkeling (1994). Productiecentrum TNO/NOTA: Delft, ISBN 90 346 290 31 (in Dutch).

**Case Study 3**

**ZEBAU GmbH**
Germany and Sweden

# Eco-buildings – European projects for ecological building, Germany and Sweden

## 1 The Importance of the Building Sector

### Introduction

The production and use of buildings and infrastructure represents a considerable portion of the material flows and resource use in our societies. The housing sector is typically responsible for close to 40% of total energy use, and construction work places for a large part of solid waste and material flows. The introduction of ecological methods for building and living is therefore essential to sustainable development. Below a number of projects with this purpose will be described and a few general conclusions drawn.

### The Life cycle of a House

The life cycle of a house consists of resource extraction, the construction of the building itself, the use and maintenance of the building, and finally its demolition.

The *resource extraction* of the material for a house is an important phase, since different building materials have very different ecological rucksacks. Considerable dematerialisation may be achieved merely by selecting better materials. Also, the transport of materials to the building site is important and may give rise to substantial environmental impact.

The *construction phase* also constitutes an opportunity for improvement in many cases. It should be noted especially that construction waste is a large share of solid waste in our societies. With proper care and planning this can be reduced dramatically and in fact almost eliminated (See Chapter 10).

The *use phase* is normally by far the most important for the resource use and environmental impact of a building. It may last for very many years; it includes most importantly energy for heating (and cooling) the house. It is obvious that, in the design of a building, not only its appearance, but even more so its use, should be in focus. Here the existing education of architects leaves much to be desired.

Traditionally *the demolition* of a house was not much of an environmental concern, since the material could be reused for new buildings or burned for energy purposes. In more modern houses, and especially houses built in the period about 1930 and 1980, this may be very different. Many buildings from this period contain asbestos in large amounts, have PCB in seals of building elements, and contain lead or other heavy metals in electric cables. The problems with these and other toxic materials may appear long before demolition if the houses are renovated. In particular old industrial buildings may be a big problem during renovation if one suspects toxic material. It may be very costly, require extensive monitoring, and give rise to considerable amounts of hazardous waste.

### The Weak Link in House Design

When developing infrastructure in general the connections between the user and the producer are strong, and the producer has to fulfil a number of criteria for construction. This is not often the case with houses for living. In this respect houses for living are more similar to ordinary products offered on a market. The market, however, does not work in the same way for houses as for products. The selection of a particular house or apartment is done for many reasons other than its quality or function. It is more often related to where the house is situated, the costs of living, the availability of apartments of the size needed, etc. Those who will use a house or apartment seldom have an opportunity to influence its construction. Instead it is the developer who sets up the requirements for the builder. Those requirements more often have to do with economy of production – the cheaper the better – than function and maintenance. Then ecological criteria become unimportant. This so-called *implementation gap* is a serious problem in the development of ecologically good housing.

Sometimes however this is gap is bridged. Ecologically good housing projects are typically promoted by local authorities, by NGOs or through private initiatives, seldom by builders or developers.

In Hamburg a *self-built programme* has successfully promoted direct contacts between future users of residential houses and the builders. The projects in the programme are supported by the city of Hamburg and rely on properties, plots, owned by the city. The future users often aim to reduce costs by contributing to the construction work personally. At the same time they are participating in the design of the buildings and of course consider carefully how future life in the buildings may be improved. Such self-built projects, in spite of – or perhaps because of – the efforts to reduce costs, have typically been in the forefront of ecological building. Energy costs, and also social settings of the new buildings, have been seriously addressed and optimised. The self-built approach is old and exists in many places.

In Malmö, Sweden, the project *frivilligdialogen* has been devised as a voluntary dialogue between builders (developers) and city representatives on energy standards in buildings. In practice, the city has few strong means to force a builder to adapt a specified energy standard in the planned building. Thus voluntary means are used. Future European Union energy licensing of new buildings will introduce minimum legal requirements.

### Sustainable Architecture

Architecture has addressed the sustainability challenge in what is called sustainable architecture. Items most often addressed under this heading include energy and heating, indoors climate, ventilation, lighting, and materials selection. Regrettably, sustainable architecture seems not to have a strong position in traditional architecture curricula.

A house promoted by sustainable architecture considers how the house is positioned relative to the compass points. It has larger windows to the south and smaller to the north. The planning of the rooms is such that daylight contributes essentially to the lighting. Often part of the house has an opening between two floors to allow more light to enter and improve ventilation. Houses are often self-ventilated. Energy use is much less than average, and may rely at least partly on clever use of sun and solar panels.

The indoor climate in sustainable architecture houses is typically very comfortable. In several cases, particularly at work places such as offices, arrangements are made to allow flowing water inside the building. The use of indoor green plants is promoted.

Buildings developed according to the concepts described include e.g. the Department of Technology and Natural Sciences of Kalmar University in Kalmar, Sweden, and the main office of Scandinavian Airlines north of Stockholm, Sweden, as well as a series of residential housing areas in e.g. Germany and the Netherlands.

## 2 Resource Use and Construction Materials

### Choice of Materials

There is a great variety of construction materials used and only a few comments on these are possible here. Among the most common building materials are concrete, wood, brick and steel. These materials have quite different environmental profiles and life cycles.

*Concrete* is one of the most important building materials. It is a mixture of sand, gravel and crushed stones, and cement. Some 5% of global carbon dioxide emissions originates from cement production, about half from calcination and half from combustion when the raw meal forms cement clinker in a kiln at 900-1500 °C. The energy consumption of the cement industry is estimated at about 2% of the global primary energy consumption, or almost 5% of the total global industrial energy consumption. Concrete is also a heavy material to transport and thus leads to environmental impact during transport, as well as wear on roads.

*Bricks and tiles* made out of clay are important in European building traditions. The conversion of the clay in the kiln to ceramic produces, as well as drying and firing, consumes considerable amounts of energy, mostly as natural gas or fuel oil, and gives rise to emissions of e.g. hydrochloric, hydrofluoric, sulphuric acids and most importantly carbon dioxide. Clay-based material is used for a large variety of purposes, for the construction of walls, roofs and in the buildings as tiles on floors, walls etc.

*Wood*, in comparison, has less environmental impact. Wood was not used for multi-storey houses for a long period due to the risk of fire in cities. With proper safety measures, however, since the 1990s this is much less of a problem and wood is again an alternative for regular construction work. Wood is less heavy than concrete and compared to concrete the building of wooden houses corresponds to a considerable dematerialisation, about 50%.

*Iron* is a material that is needed in many situations. It can, however, today be replaced in many of its traditional functions, e.g. by beams made of wood.

## Wooden Houses

In the Bo01 area in Malmö, Sweden several wooden houses were erected as demonstration projects. The house built by *Ekologibyggarna*, consisted of pre-fabricated solid wooden elements which were assembled on site. In the same area Skanska, one of the largest construction companies in the Baltic Sea region, built a whole block of three- and four-storey wooden multi-family houses. It is one of the first modern examples of a complete block of multifamily houses built entirely of wood. Also boards of wood were produced (to replace the more often used gypsum boards) and mounted on the houses to achieve a smooth facade. Thus the whole building was recyclable.

The upstream environmental impact of wooden material has been carefully studied in a project by the Swedish Wood Institute. The results prove the impact to be small and that all energy and material involved can be renewable.

**Figure 3.1 Multi-storey wooden houses.** *One of the many advantages of multi-storey wooden houses, here being built outside the Swedish city of Norrköping, is many times lower consumption of the natural resources, less handling of heavy material, easy transport etc. Photo: Holger Staffansson, Skanska.*

The *House of Design* in Hällefors, Sweden, opened in 2005, was carefully designed to achieve dematerialisation. According to a first evaluation it is a factor 1.85 house. This means that close to 50% or about 18,000 tons less material was used. It illustrates the dramatic potential the building sector has in reducing material flows. Here dematerialisation was mostly achieved carefully selecting the best material possible, e.g. from local suppliers.

## Other Materials

A building has hundreds of different materials. These make up the building itself, as well as its walls, carpets, ceiling materials, equipment, furniture, lamps etc. its water, sanitary and electric installations, and its surface treatments with varnish, paints etc. The choice of right material is an important aspect of ecological construction. It may also be important for the wellbeing of those living and working in the house.

The choice of materials can today be supported by extensive databases (see Box *Tools for Ecological Buildings,* page 294). A guide how to work with material selection is available on the US Dept of Energy web site. A guide to healthier material is provided by the Healthy Building Network Green design and construction standards.

One particularly interesting aspect of this is carpets and flooring materials. Environmentally safe carpets are produced today. One source is the Building For Health Materials Center, a national and international provider of healthy and environmentally friendly alternatives to standard construction materials.

## The Building Site – Transportations

Considerable environmental benefits can be gained by proper management at the building site itself.

Transport of materials to the site of construction may be a very important part of the entire environmental impact from the building phase. By using local and regional materials as much as possible transport is minimised. This is especially relevant if the material is heavy. Brick may often be produced locally in the entire Baltic Sea region. In the northern parts also production of wood building material may be fairly local. One may also specify the requirements of trailers, equipment, storage, and traffic at the building site. It is also important to monitor construction site energy and water use, and develop a construction waste management and recycling plan.

In the building of the Kronsberg area (at Expo 2000) in Hannover, Germany, an agreement was made with the companies to reduce transport and use local producers when possible. In addition all soil removed was deposited locally to create small mounds etc, much used for childrens' playing grounds. A similar approach was adopted for the extensive rebuilding of residential areas carried out in Hällefors, Sweden.

## 3 Building Low and Passive Energy Houses

### European Energy Efficient House Projects

The current internationally recognised standard of heating energy demand for new buildings is 100 kWh/$m^2$a. This is equivalent to e.g. German Heat Protection Regulation EnEV 2002 and the Swedish Construction Standard SBN. But it is possible to be much more efficient. A number of projects have proven that it is possible to build very low energy houses. Projects of low or passive energy houses include the ALTENER programme of the European Commission in which 12 European cities take part, the Lindåsen project in west Sweden, and the BedZED, the Beddington Zero Energy Development of energy-efficient mix of housing and work space in Beddington, Sutton, UK (see Internet Resources).

One of the first European projects, CEPHEUS (Cost Efficient Passive Houses as EUropean Standard) coordinated in Hannover, Germany, tested and proved the viability of the Passive House concept at the European level. In 2001, when the project was finalised, a total of 221 housing units in 14 building projects in Germany, Sweden, Austria, Switzerland and France had been built to Passive House standards and were in use. The scientific evaluation concluded that CEPHEUS was a complete success in terms of: the functional viability of the Passive House concept at all sites; actual achievement of the heat savings target, with savings of more than 80% already


**Figure 3.2 Passive energy houses.** *The Solar Building Exhibition Hamburg 2005.*

in the first year; practical use of Passive Houses standard in a broad variety of building styles and constructions; project-level economics; and satisfaction of the occupants of the buildings.

The Solar Building Exhibition Hamburg 2005, to be described below, was part of the ALTENER programme implemented in 6 countries in Europe. In two areas in Hamburg: Hamburg-Heimfeld and Hamburg-Wilhelmsburg, either passive houses or very low energy houses were constructed. An external quality control was organised with the help of Hamburg Building Authority in order to achieve, if possible, a faultless higher standard in comparison with ordinary new buildings. The monitoring of the energy planning and construction was originally done by the Technical University of Hamburg-Harburg and since the beginning 2005 the Detmold Low Energy Institute, while the inspection of the construction work was done by the Low Energy Institute.

## Passive Energy Houses

A passive house is a building in which a comfortable interior climate can be maintained nearly without active heating and cooling systems. The house heats and cools itself, hence "passive".

According to European standards a passive house is a house, whose need for heating, i.e. annual amount of heating, is not higher than 15 kilowatt hours per square meter and annum (kWh/m$^2$a). In a 150 m$^2$ house this amounts to 2250 kWh/a, and corresponds to 225 liters of oil or 225 m$^3$ gas. Warm water consumption, the electricity consumption as well as losses in heat production and distribution are not included in the energy balance. With this as a starting point, additional energy requirements may be completely covered using renewable energy sources. The combined primary energy consumption of the living area of a European passive house may not exceed 120 kWh/m$^2$a for heat, hot water and household electricity. The current Passive House standard was developed for Northern (heating load dominated) climates and indeed most existing passive houses are found in Austria, Germany, northern France, Sweden and Switzerland.

The combined energy consumption of a passive house is less than the average new European home requires for household electricity and hot water alone. The combined end energy consumed by a passive house is therefore less than a quarter of the energy consumed by the average new construction that complies with applicable national energy regulations.

In Germany the heating demand for a passive energy house is calculated using the PHPP software (passive house project package, Dr. Wolfgang Feist, Passive House Institute, Darmstadt). The following factors are included in the calculation:

- Heat losses over the building cover (control areas and heat bridges).
- Heat losses through ventilation subtracting heat recovery by a heat exchanger and the containment of the building.
- Heat recovery through passive solar heating through windows.
- Heat recovery from people, equipment, hot water, etc.

This method of calculation is used e.g. when applying for loans for construction in Germany.

## Very Low Energy Houses

A very low energy house, also called a KfW-40-house, should fulfil the following requirements:

1) The specific transmission heat loss must be at least 45% lower than the upper limit of the German Energy Economy Establishment (EnEV) standard valid for the building. The calculation of the need for heating for a KfW-40 house is carried out according EnEV software. Ventilation losses as well as solar and internal recoveries are not taken into account in this case. The heat losses can consequently only be reduced by improving the insulation of the building, or by using smaller windows, or windows with lower U values, and the reduction of heat bridges. Heat losses indicate primarily this "construction heat protection" and can only be taken as an indicator for the general energy saving.

**Figure 3.3 Building of a passive energy house.** *The house is insulated to achieve a U-value that does not exceed 0.15 W/m$^2$K (0.026 Btu/h/ft$^2$/°F) which typically corresponds to 20-40 cm of insulation.*

2) The primary energy consumption may not exceed 40 kWh/m$^2$ of the usable floor area and year. This includes heating, hot water and electricity, all losses during transformation and distribution, and added the contribution of other sources such as active solar technologies. The demand for a low primary energy use can be met by a low need for heating, as in the case of the passive house, or by a particularly efficient or renewable energy supply.

The requirements of the KfW-40 houses originate from the promotional program "ecological construction" of the Kreditanstalt für Wiederaufbau (KfW) (Credit Institution for Reconstruction in Berlin), which provides reduced construc-

## Tools for Ecological Buildings – Life Cycle Assessment Tools for Buildings and Architecture

For building professionals, LCA applications become most useful when a database of product information has already been assembled from which to compare products or building assemblies.

In early design phases, a whole-building analysis can help with basic questions like structural system selection. In later phases, product-to-product comparisons can help fine-tune a building's environmental performance.

Most of the information below was extracted from **Architecture on-line**, a leading architecture reference site on the web, as well as from the individual webpages.

*http://www.architectureweek.com/2003/0813/environment_2-2.html*

**Greening the building life cycle** is a collection of links for LCA software and databases for building and construction work established by the Department of Environment and Heritage of Australia. The collection is global and very useful.

*http://buildlca.rmit.edu.au/links.html*

**Idea** is an interactive database for energy-efficient architecture developed by the Dept. of Building Physics and Solar Energy at University of Siegen, Germany. The site features a some 60 building projects with photos, detailed description of concepts, plans etc. It carries a series of tools for construction of energy efficient buildings.

*http://nesa1.uni-siegen.de/wwwextern/idea/main.htm*

**LISA** (LCA in Sustainable Architecture) is a simplified streamlined LCA decision support tool to develop optimum construction systems by the Centre for Sustainable Technology, University of Newcastle, Australia. Some 20 cases with LCA data are shown. Software and cases can be downloaded.

*http://www.lisa.au.com/*

**Envest II** is a whole building LCA created by BRE Sustainable Consulting for application in the United Kingdom in 2003. LCC is a major addition to its environmental analysis capability. Envest II consolidates assessment results into the eco-points scoring system, with a single point scale for the building. It has UK regional data, cost basis, construction methods, and regulatory information built in.

*http://www.bre.co.uk/service.jsp?id=52*

**Estimator** (**Environmental Impact Estimator, EIE)** is the only North American software for life cycle assessment of buildings. Released in 2002, the software covers 90 to 95 percent of the structural and envelope systems typically used in both residential and non-residential buildings. It has databases for energy use and related air emissions for on-site construction of a building's assemblies; for maintenance, repair and replacement effects through the operating life; and for demolition and disposal. Demo version available.

*http://www.athenasmi.ca/tools/index.html*

**Athena** Life Cycle Inventory Product Databases is a material life cycle inventory database developed by the Athena Sustainable Materials Institute (SMI) based in Ontario, Canada, together with the Environmental Impact Estimator (EIE) software. The database represents a major activity of the Institute to provide model users with a great level of detail and specificity. The data are mostly from Canadian sources, with an option of specifying U.S. average.

*http://www.athenasmi.ca/tools/database/index.html*

**LEED** rating system for lowering environmental product impact awards points for recycled content, local, and low-VOC materials. In reality, it's not always easy to do select right thing. LCA can identify areas where the simple LEED-approved response may not actually be the most sustainable.

*http://www.usgbc.org*

**BEES 3.0** from the National Institute of Standards and Technology allows users to selectively apply weighting factors to environmental and economic impact, and then to weight various environmental factors such as water intake, fossil fuel depletion, or ecological toxicity. A direct comparison of alternatives is displayed as either a chart or graph. BEES has about 200 products in its database, heavily represented by carpet and flooring products.

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

**Eco-Quantum** is a residential-only analysis tool from the IVAM consultancy affiliated to the University of Amsterdam, the Netherlands. An demo is available in English on the web site.

*http://www.ivam.uva.nl/uk/*

tion loans for particularly energy-saving houses (see Internet Resources).

The calculation of energy demand should be made according to the EnEV software, not those of the PHPP. This is important, since the need for heating a KfW-40 house can vary greatly. Depending on the house technology and kind of fuel, it can approximate a passive house or be considerably higher.

The minimum insulation standard of a KfW-40 house is still considerably less than for a passive house. Solar benefits and efficient ventilation are relatively unimportant for the KfW-40 house. The primary energy consumption requirements can most often be achieved by using renewable energy sources, such as pellet furnaces. This was frequently the case at the exhibition. The costs connected with that can make heating costs three or four times higher than for a passive house, despite a low level of primary energy consumption.

## Renovation of the Built Environment

The toxic and persistent substance polychlorinated biphenyl, PCB, has been used in buildings especially in connection with the massive production of cheap housing in the 1960s and 1970s in the Baltic Sea region. PCB was outlawed in Sweden in 1972 and soon thereafter in the other countries in the region. It is now on the black list of chemicals. It was used mostly to seal the space between concrete elements and between these elements and windows. Likewise asbestos has been used for building purposes for more than 100 years. It became very popular since it did not require and maintenance and was used for facades and as roofing material. Asbestos was also used in roofing materials and in paint. As asbestos causes lung cancer if inhaled, the security arrangements when removing asbestos elements from buildings are rigorous.

In Sweden *Solna bostäder Inc* developed technology to deal with these material in renovation of the building area Blåkulla from the 1960s .

## How to Build a Passive Energy House

To meet the current Passive House standard, the construction of the houses must follow certain general principles, here briefly explained:

*Highly insulated building shell and compact form.* All components of the exterior shell of the house are insulated to achieve a U-value that does not exceed 0.15 W/m$^2$K (0.026 Btu/h/ft$^2$/°F) which typically corresponds to 20-40 cm of insulation.

*Southern orientation and shade considerations.* Passive use of solar energy is a significant factor in passive house design. Shading is absolutely necessary in all climates with high levels of solar radiation.

*Highly insulated windows.* Windows are constructed of low-e triple glazing (U-value of 0.75 W/m$^2$K and a solar transmission factor of 50%) and highly insulated frames (U-value of 0.8 W/m$^2$K).

*Elimination of thermal bridges.* By suitable application of insulation, linear thermal transmittance is reduced to below 0.01 W/mK (exterior dimensions).

*Air-tight building shell.* Air leakage through unsealed joints must be less than 0.6 times the house volume per hour at 50 Pa. This should be checked with a blower door test.

The house has forced ventilation with exhaust air heat recovery.

If comfortable indoor climate conditions differ greatly from outdoor conditions, it is always recommendable to use a ventilation system with heat recovery (or vice versa with cold recovery) to maintain a high indoor air quality without the need for huge heating or cooling demands in accordance with ISO 7730 for a definition of "comfortable indoor climate".

Passive houses have a continuous supply of fresh air, optimized to ensure the comfort of those living in the house. The flow is regulated to deliver precisely the quantity required for excellent indoor air quality. A high performance heat exchanger (efficiency > 80%) is used to transfer the heat contained in the vented indoor air to the incoming fresh air. The two air flows are not mixed. On particularly cold days, the supply air can receive supplementary heating when required. Additional fresh air pre-heating in a subsoil heat exchanger is possible, which further reduces the need for supplementary air heating. Fresh air may be brought into the house through underground ducts that exchange heat with the soil. This preheats fresh air to a temperature above 5°C (41°F), even on cold winter days.

Finally it should be added that the building companies contracted to build the area agreed to refrain from using fossil fuels. Likewise, fossil fuels were abandoned on the exhibition sites of Heimfeld and Wilhelmsburg. Thus no gas and oil is used.

The shift from conventional energy demands to solutions described here is not necessarily very expensive. It is sufficient to minimize energy use with simple systems from conventional sources. The passive house is the most energy efficient standard with only 10% additional construction costs in Germany and a very good combination with renewable energy supply.

There is always the possibility of finding your individual energy standard using the principles of the passive house idea. But don't forget, if you build your energy efficient building 20 km away from your office and there is no chance to use public transport, the energy demand for the car is as high as PE-electricity.

### The Zero-energy House in Lindåsen

Another example of passive houses is found in western Sweden, close to Gothenburg, in an area called Lindås Park. These houses do not have any heating systems. The thickness of the walls is 40 cm (compared to 20 cm present standard). It allows the houses to maintain 20°C indoors through a combination of measures. These include heat recovery from outgoing air in a heat exchanger, the body heat of the residents, solar radiation and other internal gains such as heat from compressors in refrigerators.

This project has inspired many followers. In particular it is interesting that in many places throughout the country today multi-family passive energy houses are being built.

## 4 Using the House – The House as an Ecosystem

### The House and the Site

Building and living ecologically in harmony with nature must always begin with an adjustment to the topographical conditions. Nature should be an ally and not an enemy. Thus it is preferable to have large windows to the south and smaller to the north, both for light and heat preservation. The prevailing wind direction is important for ventilation.

The house we live in may be seen as an ecosystem of its own. It is a system with in- and outflows of materials and energy. An important objective is to minimize these flows, clean them and improve re-circulation. Solutions which reduce the amount of energy, water and waste that are needed to sustain our daily lives will yield environmental and economic benefits.

**Figure 3.4 Solar panels.** *Warm water may be provided by using solar panels, a solution which is growing more economically competitive as the technology develops.*

The way the house relates to the sun is important as in all ecosystems. Thus an ideal house is much more open to the south than the north. It uses the opportunities to produce warm water through solar panels and maybe also electric current through photovoltaic (solar) cells.

### Total Energy Supply in a Built Area

Energy flows can be minimised in several ways. Little or no energy is needed for heating in passive energy houses (see above). Warm water may be provided by using solar panels, a solution which is growing more economically competitive as the technology develops. Also electricity may be provided locally as is more often the case through photovoltaic cells.

The buildings of the Solar Building Exhibition Hamburg 2005 were, on the average, well insulated, well sealed and equipped with ventilation units, mostly with efficient heat recovery. The need for heating and expected consumption of heating energy was therefore considerably lower than in normal new houses. The living comfort is noticeably higher. However support heating was available as in Heimfeld the houses were supplied with three central pellet heating boilers, used for a common heating system. This system was supported by thermal solar panels. In Wilhelmsburg many houses were heated by pellet furnaces or heat pumps, each supported by thermal solar panels. Energy for hot water and heating was thus provided from solar collectors, wood pellets or heat pumps.

The electricity need for the two areas was partly met by two big photovoltaic plants.

### Water Supply

Water use per person in western Europe is typically close to 200 litres per day and person. In Poland, Estonia, Latvia and Lithuania water was previously free of charge and consumption huge, over 400 lit/day cap. With increasing fees, however, water use has been reduced to close to 100 litres per day and capita. It is unlikely to go much beyond that without special measures.

Further conservation of water can be achieved in several ways. One is the reuse of so-called grey water (from shower, washing etc) for toilets. Another is the collection of rain water. Installations for water re-circulation within a household or multi-family house are available commercially.

Water use is normally not a problem in the Baltic Sea region except for in the southern parts, in Poland and Germany, where water conservation is sometimes important. It may also be worth while reducing water use in situations where isolated houses in the countryside have limited access to water.

## Waste and Nutrient Flows

Organic waste includes toilet waste and compostable organic waste. Toilet waste in conventional systems leaves the house as sewage. However it is also possible to do this differently, on the basis of either an individual household, a multi-family house or a neighbourhood.

Urine may thus be collected separately using a urine separating toilet. The urine contains most of the nutrients in toilet waste and if taken care of directly reduces the load on a wastewater treatment considerably. Urine can be collected in a large container and may be used yearly for gardening or by nearby farmers to fertilise agricultural fields. The rest of the toilet waste may be also taken care of locally e.g. in composting toilets. However this is less common. If urine is going to be collected separately it best to consider already when the house is constructed.

Composting of garden and food waste is increasingly common and has a very long tradition, as it was normal in older times. Because of the EU waste directives the proper collection and treatment of organic waste will be required. On a municipal level, organic waste may also be used for the production of biogas.

Separation of other forms of solid waste does not require special arrangements of the building itself, only that proper waste management is observed.

## Ventilation

Ventilation is the system in the house which influences the indoor climate more than any of the other systems. It is also the system that most often leads to complaints. Thus designing a well-functioning ventilation system is crucial. A good ventilating system should provide a good indoor climate, about 20°C and some 50% humidity, generate no sound (especially no infrasound), and have low emissions of pollutants, especially particulates.

We do not ventilate our houses because of our need for oxygen. Houses do not have oxygen deficiencies. Nor do they have a noticeable excess of carbon dioxide. In fact we ventilate to get rid of surplus heat, surplus humidity, some chemical emissions and body odours. Some of these needs can be addressed by other means than ventilation. Proper management of heat, e.g. low energy lamps and better stoves, lead to less extra heat, proper management of showers to less extra humidity, and more green plants improve the indoor climate.

Some of these problems are typical only of offices, schools etc. Heat removal is thus necessary for such buildings. Work places typically exchange the entire indoor air volume once per hour and this is thus a very considerable mass flow, consuming much energy if not taken care of properly.

The preferred ventilation system is today self-ventilation, which is a wind-driven air exchange. To make this work well, regulation of self-ventilation is needed. In particular it is important to take proper care of the heat content of the air leaving the buildings and thus make the house energy efficient. Wind-supported ventilation uses the minute differences in pressure that is produced by the wind forces. Tightly insulated buildings with rather high ceilings or even sometimes connections between two or more storeys support self-ventilation.

The indoor climate in properly designed and maintained buildings with self-ventilation may be very pleasant. It offers the living standard that we would like to see in future ecological living.

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## References

Feist, W. and Adamson, B. (1989). *Design of Low Energy Houses in the Federal Republic of Germany*. Lund University, Report BKL.

Michael, K. (2005). *Construction Quality Control of the Solar Construction Exhibition Hamburg Detmold*. Low Energy Institute, Final report 2005.

Granvik, M., Wlodarczyk, D. and Rydén, L. (2003). Building a Sustainable Neighbourhood – Kronsberg. In *Building and Re-building Sustainable Communities, Superbs report Volume II*, Rydén, L. (ed.). Baltic University Press: Uppsala, Sweden.

Bokalders, V. (2003). *Ekobyggspecial Ventilation*. Kretslopp 3/4 2003 (in Swedish).

## Internet Resources

### SmartLIFE – Sustainable Growth Solutions

http://www.smartlife-project.net

### Tiles and Bricks of Europe (TBE) – Stay with Clay

http://www.staywithclay.com/default-en.asp

### House of design, Hällefors

http://www.hellefors.se/formenshus/engelsk/default.htm

### U.S. Department of Energy – Energy and Environmental Guidelines for Construction

http://www.eere.energy.gov/buildings/info/design/construction.html

### Healthy Building Network – Market Transformation

http://www.healthybuilding.net/market_transformation.html

### Building For Health Materials Center

http://www.buildingforhealth.com/

### Beddington Zero Energy Development (BedZED)

http://www.bedzed.org.uk

### Kreditanstalt für Wiederaufbau (KfW) – The Credit Institution for Reconstruction in Berlin

http://www.kfw.de

### Ekologibyggarna

http://www.ekologibyggarna.se

### The Swedish Institute for Ecological Sustainability (IEH) – Article by Hans Eek, EFEM Architect Design Office (in Swedish)

http://www.ieh.se/amnesomraden/energi/godex.cfm?lasmer=1&id=84

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# The Baltic University Programme

*http://www.balticuniv.uu.se*

## A regional university network

The Baltic University Programme is a network of 180 universities and other institutes of higher learning in the Baltic Sea region. All countries within or partly within the Baltic Sea drainage basin are represented: Belarus, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden and more marginally Czech Republic, Norway, Slovakia, and Ukraine.

A large network of researchers and teachers at the universities has developed. The number of individuals who have contributed at some stage in the Programme are more than 1,500. The network is coordinated by a Secretariat at Uppsala University, Sweden.

## Sustainable development and democracy

The Programme focuses on questions of sustainable development, environmental protection, and democracy in the region. The aim is to support the key role that universities play in a democratic, peaceful and sustainable development. This is achieved by developing university courses for students but also to participate in applied projects in cooperation with authorities, municipalities and others.

## Many arrangements for students

The Baltic University courses attract more than 8,000 students yearly in more than 150 student groups at close to 100 universities. The courses are run separately by each university but there is much communication between course groups. Video conferencing, audio-telephone conferencing and computer conferencing over Internet allow students from different countries to meet and discuss. During summers many different activities are arranged, including a sailing seminar on the Baltic Sea and other summer courses. Student conferences and a student parliament is organized every year.

## A variety of courses

The Programme offers a variety of courses for studies of the region, its environment, social change, and sustainable development and constitute the combined efforts of a large number of scientific experts from all over the Baltic Sea region. The course material, consists of books, booklets, and TV programs. The language is English but some material has been translated into Polish, Russian, and Latvian. Printed material, films and a website contribute to a rich learning environment for the students.

Our courses are multidisciplinary, international, problem oriented, based on ongoing research at the participating universities and they all have an element of regional studies. This book is one in a series of four on environmental management and also the basic material for a Baltic University course.

*The Baltic University Centre at Belarusian National Technical University in Minsk (Photo: Lars Rydén).*

*Lecture on the ship S/Y Fryderyk Chopin while sailing the Baltic Sea (Photo: Agnieszka Trzupek).*

Read more about The Baltic University Programme at http://www.balticuniv.uu.se/

# *The Baltic University*
# Environmental Management Courses

Environmental Management is a package of four courses on master level for higher education in the Baltic Sea region. The courses convey knowledge of environmental management in all kinds of organisations, particularly in the industrial sector, and describe how environmental issues are addressed by different stakeholders in a society. The courses describe the environmental authorities and the legal and economic tool used for inspection and control, including the directives of the European Union; the formal management systems, such as ISO 14001 and EMAS, applicable to all kinds of organisations; industrial production and how to reduce environmental impact and increase resource efficiency; finally the design of products and how to asses the complete life cycle of products in society.

The courses provide a platform for environmental management education in all parts of society. They are well suited for competence development of professionals.

The four partial courses each have a course book, accompanied by a CD containing films, work tools, databases, material for training, and the textbook in PDF-format.

Each course corresponds to 7.5 ECTS credits, or the whole set to six months full-time studies.

## Web support

The web page of the course package features teaching guides for teachers and additional material for students, such as proposed tasks for group work. The links in the books are kept updated on the web page, and new links are added. Figures etc. from the books may be downloaded to be used in PowerPoint or other types of presentations.

*You will find the web pages for the EM courses at http://www.balticuniv.uu.se/ under the menu: Courses/ Environmental Management.*

## 1. Environmental Policy

### – Legal and Economic Instruments

This course describes legal and economic policy instruments, including environmental impact assessment, environmental legislation permits, and inspections and controls. Special emphasis is made on how companies and organisations can work to improve environmental performance and quality themselves, e.g. by green labelling, certification, and proper management tools. The role of inspections, both for control and in consultation to improve environmental performance in a company, is discussed. Environmental fines and taxes, although mostly of national concern, are described. The EU legislation is treated in some detail as well as the most important national legislation.

| | |
|---|---|
| *Course book:* | *Approx. 220 pages; theoretical part and cases.* |
| *Films:* | *Cases from Sweden and Lithuania (on CD).* |
| *Data base:* | *Central legislative texts (on CD).* |
| *Website:* | *Teachers' guide and group work for students.* |

## 2. Cleaner Production

### – Technologies and Tools for Resource Efficient Production

Cleaner technologies refer to production processes where pollution is minimized at the source and efficiency of resource use is carefully improved. The course describes a series of production processes and how to improve energy, water and material resource management and improve production technologies. It describes how the implementation of cleaner technologies not only improves environmental performance, but also economic viability and the quality of the production process.

*Course book:* *Approx. 315 pages; theoretical part and 6 cases.*
*Films:* *Cases from Sweden and Lithuania (on CD).*
*Data base:* *Data bases (on CD).*
*Website:* *Teachers' guide and group work for students.*

## 3. Product Design and Life Cycle Assessment

The design of products and their use are major concerns to improve environmental performance and resource flow in society. The course treats this by applying environmental management, ecodesign and life cycle assessment techniques. A series of indicators for environmental impact are examined, throughout the life cycles of products. The techniques are illustrated by many cases of eco design, dematerialisation, use of indicators and LCA calculations.

*Course book:* *312 pages; theoretical part and 7 cases.*
*Films:* *Case from the Netherlands (on CD).*
*Data base:* *Applications for Life Cycle Assessments (on CD).*
*Website:* *Teachers' guide and group work for students.*

## 4. Environmental Management Systems and Certification

The basis of environmental management is the systematic review, or audit, of an activity in an organisation, industry, or business to map environmental impact and resource use. The course describes how this is done and gives a series of tools to reduce impact. The practicalities of ISO 14001 and EMAS certification are described.

*Course book:* *266 pages; theoretical part and 7 cases.*
*Films:* *Cases from Sweden and Germany (on CD)*
*Data base:* *Tools for EMS (on CD).*
*Website:* *Teachers' guide and group work for students.*

# Baltic University Press

*Our books are interdisciplinary, international,*
*and based on latest research*

### Environmental Science

*© 2003. 824 p. SEK 500.*
by: Rydén, L., Migula, P and M. Andersson (eds.).
**Contents:** Environmental Science is an extensive and interdisciplinary review of environmental issues with a focus on the Baltic Sea region.

### English for Environmental Science

*© 2003. 166 p. SEK 150.*
by: E. Korshuk, I. Kryba, E. Savich, P. Solovyov, A. Tamarina.
**Contents:** English language course using texts and concepts from the Environmental Science text book.

### The Baltic Sea Region – Cultures, Politics, Societies

*© 2002. 676 p. SEK 375.*
**Contents:** Regional development; history, culture, languages, democracy, multicultural societies, peace and security, social conditions and economies in the Baltic Sea region.

### A Sustainable Baltic Region

*© 1997. 10 booklets, 50 pages each. SEK 50 each.*
**Contents:** Sustainable development is treated in ten thematic booklets; energy, material flows, agriculture, industrial production, transport and habitation, ethics and law, ecological economics, and Agenda 21.

### Sustainable Water Management

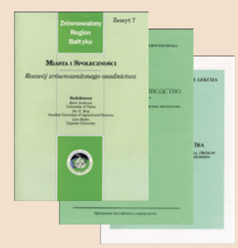
*© 2000. 3 books, 230-250 pages each. SEK 200 each.*
**Contents:** Hydrology, water quantity and quality, water management in agriculture, cities and industry, water and cities, transport, fishing, tourism and environmental protection, institutions and law, management plans, water conflicts, and international cooperation.

### Sustainable Community Development (Superbs Case Studies)

*© 2002. 4 booklets, 80 pages each. SEK 75 each.*
**Contents:** City development, energy, material flows, urban planning, transport and habitation, illustrated by 35 case studies from 10 cities in the Baltic Sea region.

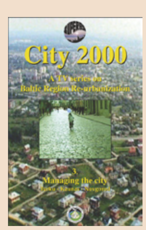
### Translations:

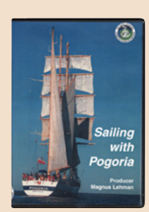
*Belarusian*
*Latvian*
*Polish*
*Russian*
*Ukrainian*

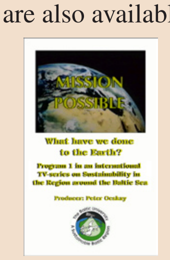


## Film material

Video tapes/CDs that add to the books, and other written material, are also available for most of the courses.




To order our books and films, please visit: http://www.balticuniv.uu.se/webshop

## The Environmental Management Book Series

Environmental issues are becoming increasingly important in all parts of society. Up till now good educational material has largely been lacking. The present Baltic University series of books, and other material connected to them, support master level training in environmental management in higher education. The books can be used for all relevant university level educational programmes, although they are especially suitable for engineering programmes.

The series is the result of a cooperation between specialists at universities and practicians in the Baltic Sea region: Sweden, Denmark, Germany, Poland, Lithuania, Belarus as well as the Netherlands. The material consists of books with theoretical backgrounds and CDs with films, cases, practical exercises, tools, and databases. It covers four courses in environmental management. A web support to the courses offers teachers' guides and student group works, as well as updated links and other material.

### *Product Design and Life Cycle Assessment*

Good design and improved life cycles of products is a key step towards sustainable production and consumption patterns in our societies. This book systematically discusses design using the ecodesign strategy wheel for improvement, redesign and development of products and services. A life cycles approach covers resource management, use, and the end-of-life of products. Life Cycle Assessment, LCA, the most comprehensive tool to assess environmental impacts, is carefully treated including information management, impact assessment methods, and the interpretation of results. LCA applications and many examples of ecodesign are included. The enclosed CD covers software and databases for LCA, cases to illustrate ecodesign strategies, and work tasks for students.

*The Baltic University Programme*

*The BUP is a cooperation between 180 universities in 14 countries in the Baltic Sea region, coordinated by Uppsala University, Sweden. The Programme develops interdisciplinary education on sustainable development and environmental science throughout the Baltic Sea region. It also works with applied projects in cooperation with governmental authorities, local administration and business, as well as with research and information.*

The Baltic University – A Regional University Network

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