1. The state of the environment

Various international status reports on the condition of the environment have been prepared over the last few decades. One report which, more than any of its predecessors, has come to shape the discussion of our civilization's effect on our common environmental basis was prepared by a commission established by the UN in 1983. The object was to prepare a status report for the relationship between environment and development in the world today, and on this background to propose a global programme for changes. The commission was named the Brundtland Commission after its chairman Gro Harlem Brundtland, who subsequently became prime minister of Norway.

The Brundtland Commission's report was given the title "Our Common Future", and it described scarcity of resources, population growth, environmental impacts and unequal distribution of economic welfare and growth as interacting threats to our common future on earth. "Sustainable development" was introduced as the only possible and acceptable development if human civilization is to avoid collapse in the near future. A sustainable development was defined as "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 43 in the World Commission on Environment and Development, 1987). With this definition of the concept of sustainability the focus was on our environment's ability to fulfil our needs and those of future generations. Included were:

- The material resources, non-renewable and renewable.
- Biological diversity, genetic resources.
- The health of the environment in which our own and future generations must live.

The concept of sustainable development can also include environmental qualities which fulfil other, more aesthetic needs, for example experiencing a varied natural and undisturbed environment.

In contrast to the earlier environmental status reports of similar nature, the Brundtland Commission's report gained major significance for the international political discussion on the human impact on the environment. The report led in 1992 to a UN-sponsored World Conference on Environment and Development (UNCED) in Rio de Janeiro.

The Rio Conference enjoyed the participation of heads of governments from 118 countries and resulted in two international treaties - one on climatic changes and one on biodiversity. A programme for international cooperation on integration of development processes and environmental considerations, which is to ensure a responsible development for the earth into the 21st century, also resulted (Agenda 21; e.g. United Nations, 1993).

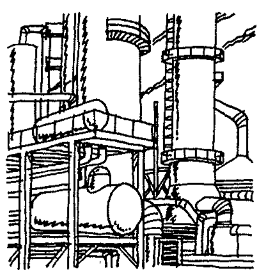
In recent years attempts have been made to define the concept of sustainable development in the form of "the environmental space", which is an attempt to quantify the resource consumption and the environmental impact which can be accommodated for the individual person without exceeding the level of sustainable development (Spangenberg, 1995).

Developments in human impact on the environment

In previous centuries human influence on the environment was of local extent, concentrated especially around urban communities, but today it is often major regions, or perhaps the entire earth, which is affected. While previous environmental impacts were of a predominantly physical character, a significant portion of today's environmental impact can be blamed on emissions of chemicals toxic to the environment.

The reasons underlying this development are:

- Constantly growing human activity.
  Over the last 40 years the industrialized countries have experienced an increase in their material standard of living which is without precedent in world history. Continued economic growth is expected for the industrialized countries, and growth in the developing countries will have to be even greater if the difference from the industrialized countries is to be reduced. At the same time, world population has grown exponentially. By mid-1995 the world's population was 5.7 billion. With an annual growth of 90-100 million, the population will double in the next 40-50 years. Population growth is stagnating in the industrialized countries but it is high in developing countries, and according to a 1992 UN prediction, world population in the year 2050 will be at least 10-11 billion (United Nations, 1992). As a result the total global production is increasing, as are the environmental impacts which the production is generating.



- Use of many new chemicals foreign to the environment.
  In the last half of the 20th century there has been an explosive growth in the number of chemicals in general use. Production has become industrialized to an increasing extent, and based on new chemicals which in most cases are foreign to the environment. Within the course of a few decades, the former chemical universe based on natural substances has been replaced by a much more extensive chemical universe based principally on petrochemistry (crude oil products). When the chemicals do not occur naturally, they can have unexpected and often unforeseeable effects on the environment, which has not been exposed to them before.

- Use of increasingly larger parts of the earth.
  Human activities are being extended to include areas which were previously pristine, and the environment over most of the earth is therefore affected. Deeper layers of the earth's surface are also being involved in human activities to an increasing extent, for example in exploration for oil, coal, gas and metal resources.

The following sections review the effects of man's current impacts on the environment. The review takes its point of departure in the damage which can be observed today or is expected in the future as a consequence of these impacts.

Firstly, a brief review of current knowledge on the effect in question is given, followed by some of the unfortunate consequences which can be expected to arise, followed finally by a summary of the initiatives which have been taken with respect to the impacts contributing to the effect.

Global impacts and environmental effects

As noted, some human impacts on nature have already reached such an extent that they are influencing all parts of the earth and may thus be regarded as global. This applies to the exploitation of non-renewable resources and it applies to chemical impacts on the environment from substances with the ability to spread to sensitive parts of the global ecosystems.

For global environmental impacts, the substances concerned include carbon dioxide, CFCs, mercury, DDT and PCBs, which share the following characteristics:

- long life in the environment, leading to wide dispersal before they are degraded or immobilized,
- high mobility in the environment, leading to transport to all parts of the global environment, including those parts which are sensitive to the substances' impacts.

The substances are often emitted in such large quantities that the effects can be seen globally, even if the substances are greatly diluted on dispersal.

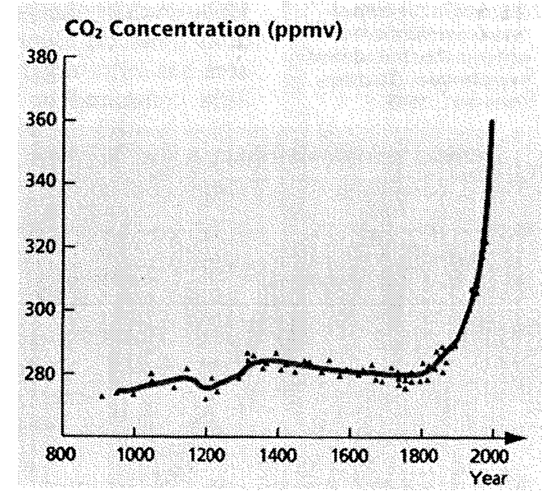


Figure 1.1. Atmospheric concentration of CO_2 during the last thousand years. The unit is parts per million by volume. After Schimel et al., 1995

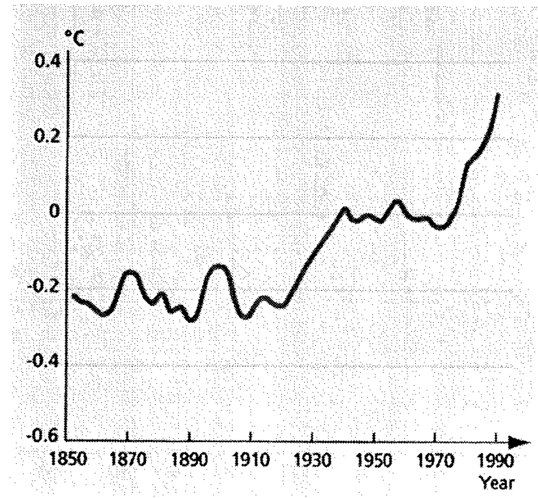
Climatic changes as a consequence of global warming

The man-made global warming is attributed to the emission of gases which retain heat radiation which would otherwise be lost from the earth into space. The gases thereby contribute to the heating of the atmosphere.

What do we know?

The atmospheric content of all of the most significant greenhouse gases has increased strongly over the last 100 years, especially after the Second World War. This is shown for CO_2 in Figure 1.1. Most of the increase is attributable to combustion of the fossil fuels oil, coal and natural gas. In the same period, the mean global temperature has increased by a good half a degree, as shown in Figure 1.2. The climate may show large natural variations, and it can therefore be difficult to identify man-made changes before they have reached a certain extent. Nevertheless, it is estimated today that the man-made global warming impact has already caused measurable changes in climate (Houghton *et al.*, 1996).

Figure 1.2. Global annual average temperature expressed as the deviation from mean temperature 1951-1980. Reproduced after World Meteorological Organization, 1991



What do we fear?
Sudden regional changes in existing climatic systems, e.g. as a consequence of a changed course in major ocean currents or a melting of polar ice caps and glaciers in mountainous areas, are perspectives causing concern. Such changes will lead to alterations in the conditions of life for man and ecosystems at a speed which will render gradual adaptation impossible. Industrialization of large parts of the Third World could increase future emissions of CO_2, the most important greenhouse gas, dramatically.

What are we doing?
The UN's 1992 Climate Convention required the 154 signatory countries to stabilize emissions of CO_2 and other greenhouse gases at the 1990 level by the year 2000. Some countries have adopted more ambitious goals. In Denmark, the Ministry of Energy's plan of action in the area has set a target for reduction of CO_2 emissions in the year 2005 by 20% compared to the 1988 level. The most important halocarbons, which are also greenhouse gases, will be phased out quickly over the next few years following special agreements concerning this group of substances (see Stratospheric ozone depletion below).

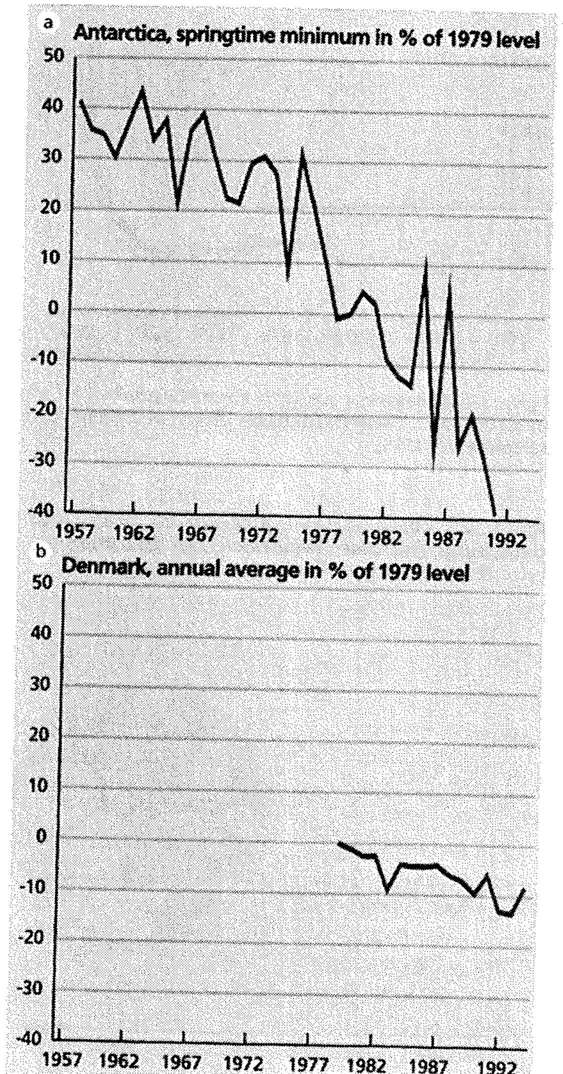


Figure 1.3. Ozone content of the stratosphere 1957-1994, with 1979 as reference year
a) Decrease in spring concentration of ozone in the stratosphere over Antarctica (Albritton et al., 1995b)
b) Decrease in the annual mean concentration of ozone in the stratosphere over Denmark (Statistics Denmark, 1995)

Stratospheric ozone depletion

Formation and breakdown of ozone were originally in balance in the earth's stratosphere at an altitude of 15-40 km, but the breakdown has been accelerated by man-made emissions of halocarbons, i.e. organic compounds containing chlorine or bromine, and which are sufficiently long-lived to reach the stratosphere. The reduced ozone level in the stratosphere means a higher intensity of dangerous UV radiation in the sunlight reaching the surface of the earth.

What do we know?
Man-made emissions of halocarbons (CFCs, tetrachloromethane, 1,1,1-trichloroethane, HCFCs, halons and methyl bromide) have led to a steady increase in the concentration of chlorine and bromine compounds in the stratosphere over the past 40 years. It has been possible over the last 20 years to confirm that the mean ozone concentration in the stratosphere has decreased steadily, apparently more rapidly in recent years. Since the middle of the 1980s, a radical depletion of the ozone layer over the South Pole (the "ozone hole") has been observed during early spring. In the last few years an accelerated depletion of the ozone layer over the North Pole has also been observed. Figures 1.3a and 1.3b illustrate the trend in stratospheric ozone content over Antarctica and over northern Europe.

Depletion of the ozone layer is accompanied by an increased intensity of the UV radiation reaching the earth's surface over large parts of the southern and northern hemispheres. Increased exposure to UV radiation can lead to increased frequency of skin cancer and cataracts and is responsible for a reduced efficiency of immune defences in animals and humans and for damage to the photosynthetic system in algae and higher plants.

Currently (1997) there is agreement that man-made halocarbons are an important reason for the depletion of stratospheric ozone. The magnitude of ozone depletion is expected to peak within the next 5-10 years and then to decrease as a result of the agreements already in force for the phasing out of halocarbons (see below). But irrespective of current efforts to slow ozone depletion, it is expected that the critical lower limit for formation of the ozone hole will be exceeded at least until the middle of the 21st century.

What do we fear?
If ozone depletion reaches the same extent over the North Pole as it has over the South Pole, large and densely populated areas in Europe and North America will be exposed to strongly increased UV radiation with associated extensive damage to health.

What are we doing?
With the Montreal Protocol and subsequent revisions (see e.g. UNEP, 1993), the international community has agreed on an unusually strong control of a group of environmentally hazardous substances. Under these agreements, the industrialized world's production and use of CFCs, tetrachloromethane and 1,1,1-trichloroethane was phased out by 1 January 1996. In developing countries the deadline for phasing out of these gases is 2010. In industrialized countries the production of halons ceased as of 1 January 1994. Production and use of HCFCs stabilized in 1996 and will be phased out by the year 2030. At the same time, the use of methyl bromide was stabilized in 1995. Some industrialized countries have further tightened these deadlines. In Denmark, HCFCs will be phased out gradually by 2002, and methyl bromide will be phased out by 1 January 1998. Even the strong CFCs will, however, continue for a long time to seep into the environment from insulating foam and refrigeration and air-conditioning systems in use and from the disposal of products such as refrigerators which are already in use.

Persistent toxicity

Over the last few decades, attention has been drawn to a number of different substances which, intentionally or unintentionally, have been produced as a consequence of human activities and which are persistent, that is, highly resistant to degradation in the environment. Some of these environmentally foreign substances also possess characteristics which enable them to accumulate in living organisms until they reach toxic concentrations. If they are also mobile in the environment and are emitted in sufficient quantities, the substances' toxicity to man or ecosystems may become a global environmental problem. The list of globally distributed environmentally hazardous substances is steadily growing, but among the best known are mercury, the insecticide DDT, the group of polychlorinated biphenyls (PCBs) and the group of dioxins and furans. In 1997 these substances amount to a global problem.

More information on persistent toxicity is provided in the section on regional environmental impacts as it is still exceptional for persistent toxicity to be of global extent.

Consumption of non-renewable resources

Many of the resources on which we base our material world are regenerated either not at all or so slowly that it is without practical significance for us. They can be regarded as capital which is not accruing any interest. We often use them in an irreversible manner, for example when we burn fossil resources such as oil and coal, thereby reducing the opportunity for future generations to use these resources to meet their material needs.

What do we know?
For several of the important metal resources, the current rate of consumption means that the exploitable reserves of ores known today will be used up in a few decades. Large parts of the Third World are currently experiencing a rapid industrialization, and a rising material standard of living can be expected for large populations in the Far East. Even if the industrialized world uses its non-renewable resources more effectively, increased pressure on them can still be expected in future years.

What do we fear?
Reduced availability of one or more important non-renewable resources can lead to international tensions, and in the worst case to armed conflicts. The industrialized world's dependence on access to large quantities of oil has thus been behind several instances of this in the last few decades, with the Gulf War in 1991 as the most dramatic to date.

What are we doing?
In large parts of the western world, attempts are underway to promote the use of such non-depletable energy sources as solar and wind energy. There is also focus in society on replacing the use of new materials with the recycling of old. But as a rule, recycling initiatives are driven by the desire to minimize the amount of waste produced in the community, rather than to save resources.

In production, there is focus in many places on minimizing consumption of materials, often for economic reasons.

Regional environmental impacts

In contrast to global impacts, regional impacts only affect the environment in the region where the source of the impact is found. 'Region' in this context means an area stretching from around 100 to 1000 kilometres, depending on the nature of the impact and the sensitivity of the environment. On a regional scale, more short-lived substances can also contribute to environmental impacts.

In contrast to the local impacts discussed at the end of the chapter, regional environmental impacts are said to be caused by "diffuse" sources, meaning that the impacts cannot be traced back to a single point source, either because they arise from sources which are far away, or because the pollution is arising as a consequence of a highly intricate network of small local sources.

Damage to forests and other vegetation

The forests in large parts of the industrialized world are suffering damage from air-borne pollution which either damages the leaves of plants or ruins the soil in which the plants are growing.

What do we know?
The damage is caused by a combination of different influences which have an impact on plants. Some of the influences are man-made:

- Emission of acidifying compounds, especially sulphur dioxide, oxides of nitrogen and ammonia, which attack leaves and acidify the soil. In large parts of Europe, critical loads for acidification have been exceeded in forest soils.
- Emission of organic compounds which are broken down in the atmosphere with photochemical formation of ozone and other reactive compounds which attack leaves.
- Emission of nitrogenous compounds, especially ammonia and oxides of nitrogen, which fertilize forest trees into a forced growth and create the basis for an altered species composition in nutrient-poor ecosystems, e.g. heathlands and raised bogs. In many parts of Europe the critical loads for nitrogen enrichment have been exceeded.
- Increased intensity of UV radiation caused by stratospheric ozone depletion damages the photosynthetic organelles in leaf cells.
- Extreme climatic conditions such as drought and high winds damage perennial plants in particular. The frequency of such climatic extremes may already be increased as a consequence of man-made global warming.

What do we fear?
Increased extent of the damage, with consequent loss of major ecological and recreational values.

What are we doing?
There is an international convention under the UN's Economic Commission for Europe, UNECE, on reduction of long-range transboundary air pollution. A number of European countries have signed separate protocols on reduction in emissions of sulphur dioxide, oxides of nitrogen and volatile organic compounds (UNECE, 1991). The agreements have led to significant reductions in SO_2 emissions from many countries, while emissions of volatile organic compounds and oxides of nitrogen are largely unchanged for most countries due to a strong growth in road transport over the last decade, which more than offset the improvements achieved in control of car engine combustion processes and in the treatment of flue gases from coal-fired power plants.

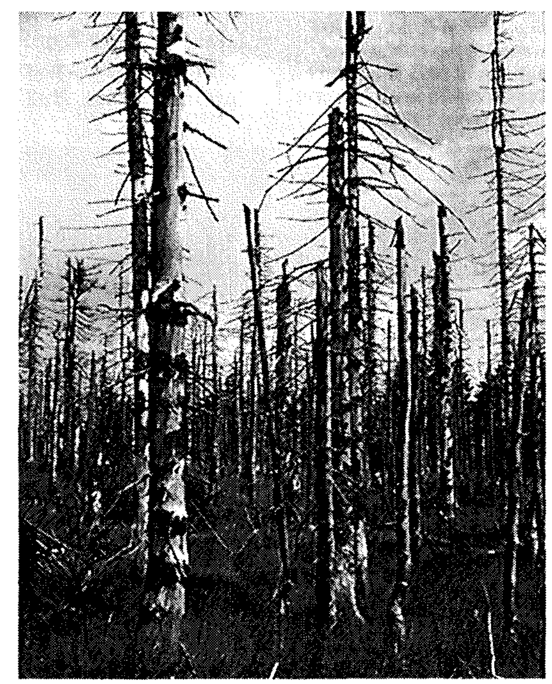


Figure 1.4. In extreme cases the damage from air pollution can kill the forest, as here in the Czech Republic (Photo: Biofoto)

Damage to lakes and coastal waters

Our coastal waters and many of our lakes are suffering the effects of deposition of excessive water-borne or air-borne compounds containing the nutrients nitrogen and phosphorus. In addition, many Scandinavian lakes have been acidified as a consequence of air-borne pollution.

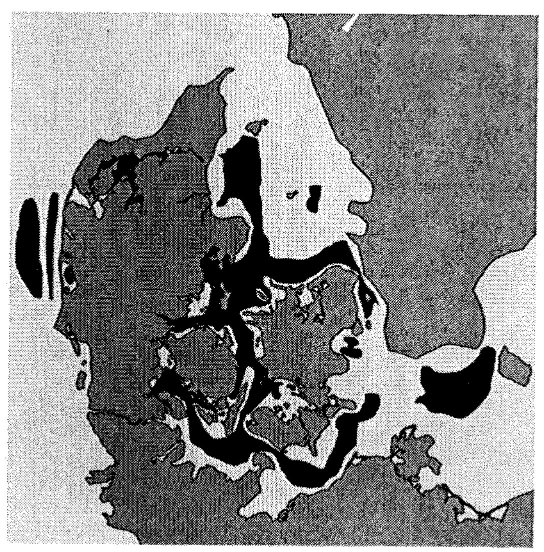
What do we know?

The growth of algae in aquatic ecosystems is most often limited by the availability of either nitrogen or phosphorus. Addition of the nutrient which limits growth causes increased growth of algae, possibly an algal bloom. This effect, known as eutrophication, has been occurring locally about towns for a long time. In Denmark, individual episodes of oxygen depletion in fjords and the Baltic Sea are known back to the beginning of the twentieth century, but in our time the eutrophication has extended much more widely. Figure 1.5 shows the extent of oxygen depletion in inner Danish waters in the summer and autumn of 1995. Oxygen depletion has been an annually recurring problem attributed to the fact that the large populations of algae occurring because of eutrophication sink to the bottom and are broken down with consumption of the oxygen in the bottom layers.

Benthic animals are thus exterminated over large parts of the sea floor. Catches of cod and plaice have fallen substantially over recent years, probably at least partly because periods of oxygen depletion are exterminating the bottom-dwelling animals on which the fish feed. The nutrient enrichment is also a contributing cause to the increased growth of various poisonous species of algae in coastal waters and lakes.

Nitrogen is normally the limiting nutrient in coastal waters. The nitrogen load is attributed particularly to leaching out from extensive agricultural areas, but air-borne emissions of oxides of nitrogen from power plants and transport also contribute significant quantities. Emissions of acidifying gases which can travel large distances are affecting sensitive lakes in large parts of Scandinavia. The clear waters of acid lakes resulting from the direct emission of acid compounds into the lakes have been known in individual cases in Norway and Sweden for almost a hundred years. But the problem has increased in extent, and today several thousand lakes are affected in Norway, Sweden and Finland as well as in central European mountain areas.

Figure 1.5. Extent of oxygen depletion in Danish coastal waters in the summer and autumn of 1995 (based on the Danish Environmental Protection Agency, 1995a)



The acidification of lakes is caused by air pollution, especially by sulphur dioxide and oxides of nitrogen, which is ultimately deposited in the lakes. A large portion of the acidifying compounds which end in Swedish and southern Norwegian lakes originates in emissions from Danish and English power plants.

What do we fear?

Further nutrient enrichment of coastal waters, but also of larger marine areas like the Baltic Sea and the North Sea, can lead to dramatic and permanent changes in the species composition of the marine ecosystems and threaten the fishing industry in these areas. Large parts of the benthic vegetation of the Baltic Sea are thus already dead, and industrialization of eastern European agriculture can be expected to further increase the impact on the Baltic Sea.

What are we doing?

Agreements have been signed between affected countries and targets have been set to limit nutrient enrichment of the marine environment in coastal waters in various regions in Europe. For the North Sea and the Baltic Sea, a reduction in emissions of nutrients by 50% is thus being sought, but these agreements have not yet (1997) had any detectable effects.

Attempts are being made to reduce the emission of acidifying substances as described above under 'Damage to forests'.

Persistent toxicity

Some of the substances emitted are not easily degraded in the environment and can build up to concentrations which cause toxic effects to man or ecosystems.

The heavy metals formerly attracted considerable attention, but over the last decade it has become clear that many different organic substances can also contribute to persistent toxicity.

What do we know?

Of the order of 100,000 industrially produced chemicals are currently registered for marketing, and thus use, within the EU (EEC, 1990). Very little or nothing is known about the behaviour of most substances in the environment and their potentially toxic effects on different organisms. For those substances investigated to date, it is clear that:

- Some substances are not easily degraded in our sewage treatment plants or in the environment, and others have been found to have stable degradation products. These substances or their degradation products will remain in the environment long after they are emitted.

- Some substances accumulate in living organisms until they reach levels at which they are toxic to the organism. One of the most commonly cited examples is the insecticide DDT, which is concentrated via the food chains in birds of prey and which previously caused thin-shelled eggs which could not be hatched. Another, more recent example is the occurrence of polychlorinated biphenyls, PCBs, and dioxins in mother's milk in women, reaching concentrations which have generated a debate on whether breast feeding of babies should be discouraged.

- Some substances have been shown to find their way into parts of the environment where they have not been expected. Recent examples are the discovery of many agricultural pesticides in ground water which is used as drinking water and the spreading of plasticizers from PVC in water, soil and air.

- Some substances have been shown to have unexpected toxic effects. An example is the recent discovery that a range of different industrial chemicals or their degradation products in the environment mimic the female hormone oestrogen (see Table 1.1).

Substances with effect as environmental oestrogens (summer 1995)	
Alkyl phenols Nonyl phenol Octyl phenol	Degradation products from detergents widely used in e.g. cleaning products and paint
Phthalates BBP DBP	Plasticizers in certain types of soft PVC plastic. Phthalates are among the most commonly found man-made chemicals in the environment
Pesticides DDT, DDE	Now prohibited in large parts of the world
Methoxychlor Lindane	Prohibited in Denmark Prohibited in Denmark
Others Bisphenol A	Component in epoxy materials and polycarbonate
PCB, some	Now prohibited in large parts of the world

Table 1.1. Substances foreign to the environment for which an oestrogenic effect has been demonstrated (Toppari et al., 1995)

The presence of hazardous substances in the environment is often cited as a probable contributor to:

- the increasing frequency of allergy in children and adults,
- increased risk of development of several different forms of cancer,
- reduced sperm counts in men in most of the industrialized world,
- reduced reproductive capacity in many of the animal species at the top of the food chains.

Currently (1997) there is, however, still no definitive proof of these assumed relationships.

We do, however, know one thing: there is much we don't know about the persistent toxicity of thousands of different substances.

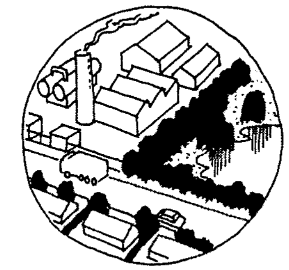
What do we fear?
The impact, and thus the possibilities of damage, of so many different chemicals is difficult both to monitor and to control. There is also the possibility of discovering new undesirable and hitherto unknown effects on health and environment from some of the many substances which we emit.

What are we doing?
Within the EU, a systematic risk assessment of the industrial chemicals which are produced and used in greatest quantities within Europe has been initiated. There are 2,000-3,000 chemicals used or imported by individual importers within the EU in quantities exceeding 1,000 tons per annum. An agreement has been reached within the EU on risk assessment of 79 chemicals (EC, 1994).

There are agreements for both the North Sea and the Baltic Sea on reduction of emissions of toxic substances by 50% from the end of the 1980s to 1995. There is consensus in the most recent agreements on the North Sea concerning the goal that emissions of environmentally hazardous substances into the North Sea must have ceased by the year 2020 (Danish Ministry of Environment and Energy, 1995).

Substances which are particularly problematic because of their persistent toxicity will be phased out gradually, as was the case for lead in petrol, or prohibited, as has been done for PCBs or the most problematic agricultural pesticides.

Local environmental impacts



Local environmental effects are those occurring about significant individual sources.

Local impacts are limited to the immediate vicinity of the source or influence, and the geographic extent of the immediate effect is therefore normally at most a few kilometres.

Physical impacts

Deforestation is one of the first serious physical impacts to which man has subjected the environment.

Today, physical impacts have reached a much higher level as a consequence of the number of people, and not least the use of machinery which increases man's capacity to do mechanical work many times.

What do we know?
Significant physical environmental impacts the world over are caused by construction works such as the building of roads, bridges and harbours. Large quantities of materials are moved and the surroundings can be affected by noise and vibrations both during the construction phase and after the finished installations are taken into use.

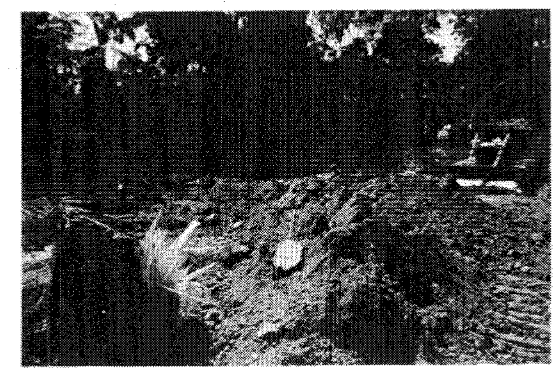


Figure 1.6. Clearing of South American rain forest (Photo: M. Hauschild)

Agricultural cultivation of the earth also has significant physical impact on the environment. Small ponds are drained and filled in so that the earth can be cultivated, thus removing the habitats of many species. To facilitate mechanized agriculture, live hedges are being removed between adjoining fields, and the remaining habitats appear as small enclaves isolated from one another, with very little opportunity for the dispersal and exchange of species. Marshes are being drained and rivers and watercourses straightened to devote the areas to the cultivation of crops, thus increasing the leaching out of nitrogen to our coastal areas and reducing the formation of groundwater.

The primeval forest in large parts of Europe has been cleared over the last 1,000 years. A similar clearing of forests is occurring today in many areas in the Far East and South America. Clearing of the primeval forest is occurring for sale of timber, cultivation of the cleared ground or mining for minerals, as was the case in Europe. But large parts of the earth's rain forest ecosystems exist on poor soil, and most of the nutrients are found in the terrestrial plant biomass. Forests hold the soil in place and are also of major significance for local climate. The clearing of rain forest therefore leads to loss of the nutrients and the topsoil, and leaves large areas barren and eroded and without scope for significant cultivation.

Table 1.2. Annual extent of rain forest clearing in various tropical countries (World Resources Institute, 1990)

Extent of rain forest clearing in tropical countries

Country	Clearing % per year	Year
Brazil	2.2	1987
Cameroon	0.6	1976-86
Costa Rica	7.6	1977-83
India	4.1	1975-82
Indonesia	0.8	1979-84
Myanmar	2.1	1975-81
Philippines	1.5	1981-88
Thailand	2.5	1978-85
Vietnam	2.0	1976-81

Among physical impacts on the environment are:

- loss of or splitting up of important habitats required by various forms of life,
- loss of aesthetic qualities and cultural assets,
- soil erosion and loss of arable land,
- lowering of the water table,
- flooding due to a reduced drainage capacity of rivers and watercourses, e.g. as a consequence of clearing of forest on mountain sides adjacent to the river, leading to major surface run-off, erosion of the slopes and increased sedimentation in the rivers.

What do we fear?
A gradual degradation of the natural environment as a consequence of a widespread occurrence of local physical impact on the environment almost everywhere on earth. One consequence is a loss of species which is particularly serious in the clearing of rain forests, which are among the most diverse ecosystems on earth.

What are we doing?
Regulation of physical impacts of the environment is being sought in many countries through various forms of regional and local planning, and in the submission of environmental impact assessments covering both chemical and physical impacts for major construction works.

Local toxicity

Local toxicity to ecosystems or humans can have the same causes as the persistent toxicity discussed above under regional environmental impacts. The probability of experiencing local effects of an emission is, however, generally greater, because dilution of the substances emitted is small in the immediate vicinity, so that the substances occur in greater concentrations on a local than on a regional scale. The higher concentrations also mean that acute toxicity can occur, i.e. toxic effects which appear shortly after the release.

What do we know?
Chronic effects as discussed under persistent toxicity can occur locally, in some cases also for substances which are not persistent. Acute ecotoxicological effects can also arise around effluent discharges from sewage treatment plants or from industry. Under unfavourable circumstances, acute toxicity to humans can occur via the breathing of air pollution, e.g. during periods of smog. In the more environmentally regulated industrialized countries, both acute toxicity and acute ecotoxicity generally occur only rarely, partly because of the extensive use of treatment plants both in industry and for municipal emissions. They occur in other parts of the world, most notably in connection with accidents, but also as acute toxicity following emission of untreated industrial effluent and municipal waste water.

What do we fear?

- New and undesirable effects from the substances which we emit to the environment.
- Technologies which expose the user to hazardous substances and which are so complicated that accidents are increasingly more difficult to avoid: wrecks involving oil tankers, accidents involving chemical transport, emissions from nuclear power plants.
- Local pollution of drinking water from leaching of chemicals or landfills.

What are we doing?
In most of the industrialized world, industry has very greatly reduced toxic emissions from production processes over the last two decades. Originally, this occurred mainly through establishment of treatment plants, later by integrating environmental considerations into production, i.e. by the gradual introduction of cleaner technologies. As a consequence of this development, industrial emissions as a whole have become much less toxic, and many industrialized countries today are experiencing no problems with acute ecotoxicity from industrial emissions. In return, the treatment plants have provided a residual product in the form of sludge from the treatment of sewage. In many cases the sludge has a content of substances toxic to the environment which makes it unsuitable as an agricultural fertilizer, and it must therefore be dumped or burned.

Monitoring of man-made pollutants in groundwater has increased. Future limit values for the content of hazardous chemicals in drinking water are under discussion within the EU.

Attempts are being made within the EU to reduce air-borne emissions from road transport by tightening requirements concerning car engine combustion processes. The effect of this initiative is, however, counteracted by a rise in road transport, especially in personal transport.

Renewable resources

Renewable resources are resources such as groundwater, populations of fish, forests and other forms of biological resources which are not depleted by man's use if they can be regenerated at the same rate. Renewable resources can therefore be used without infringing upon the resources of future generations.

As the rate of regeneration can vary greatly from area to area, use of renewable resources is regarded as a local to regional impact. It is primarily in the local areas that care can be taken that the resource is not used faster than it can be regenerated.

What do we know?
In many parts of the world, renewable resources are being exploited at a rate which will ensure that they will decrease, and perhaps disappear entirely, to the detriment of present and future generations:

- Fish populations are being depleted.
- Forests are being cleared without regard for their regeneration with the same biodiversity.
- Agricultural practices are leading to an impoverishment of the soil and loss of its humus content.
- Groundwater is being extracted faster than it can regenerate. It is being polluted by penetration of salt water in coastal areas or by the dispersion of local pollution.

What do we fear?
Permanent loss of the opportunity of using the renewable resources which are a significant basis for the functioning of society.

What are we doing?
Use of some of the renewable resources is subject to various forms of national and international regulation, e.g. international fishing agreements for protection of fish populations or national and international initiatives for the promotion of sustainable forestry.

2. Society's environmental focus

Since the beginning of environmental legislation in the industrialized world in the 1970s, considerable attention has been paid to industrial pollution. Over the last 20 years, both companies and authorities have therefore accumulated considerable experience in reducing and controlling the environmental impact of industry, and both parties have built up organizational structures for the environmental work.

Companies have directed their attention to the treatment of waste water and air pollution and the introduction of cleaner technology, and many companies have established environment departments and appointed employees with responsibility for environmental matters.

Official regulation of pollution has occurred primarily via legislation and arrangements concerning supervision and approval. An administrative system has been established to undertake this work. Official responsibility for environmental administration is divided among central and regional authorities, and the practical work is carried out by decentralized technical administrations and national environmental agencies.

Efforts have mainly been concentrated on emissions from material production, product manufacturing and disposal as illustrated in Figure 2.1.

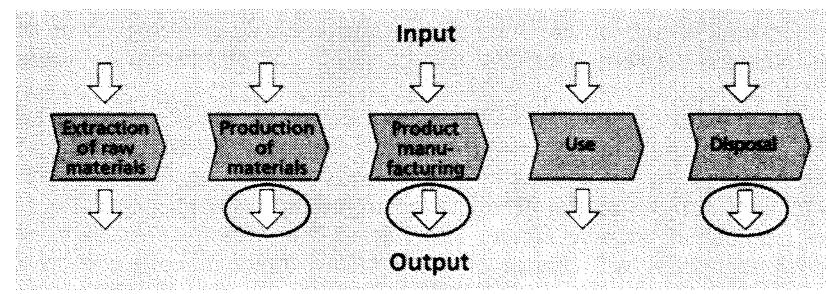


Figure 2.1. Environmental focus in the industrialized world

This focus has had a marked effect on emissions. An example for manufacturing companies in Denmark is shown in Figure 2.2a, which illustrates the development in various pollution parameters for emissions of waste water from industrial production over a 10-year period (Wenzel *et al.*, 1990). Virtually all pollution parameters in industrial waste water emissions in this period have been reduced by 80-90% for Denmark as a whole.

But at the same time, a number of other circumstances have been pulling in the opposite direction with respect to impacts on the environment. The material standard of living has been rising, and consumption of products, and therewith resources, has risen virtually in step with the falling impact of emissions from companies (Figure 2.2b).

Since environmental impacts are attributed in increasing degree to a rising supply and consumption of products, control solely on the basis of a concentrated effort directed towards individual emissions from production processes is becoming more difficult.

Even if the biggest individual emissions are reduced, the total environmental impact in some areas will still rise as a consequence of the

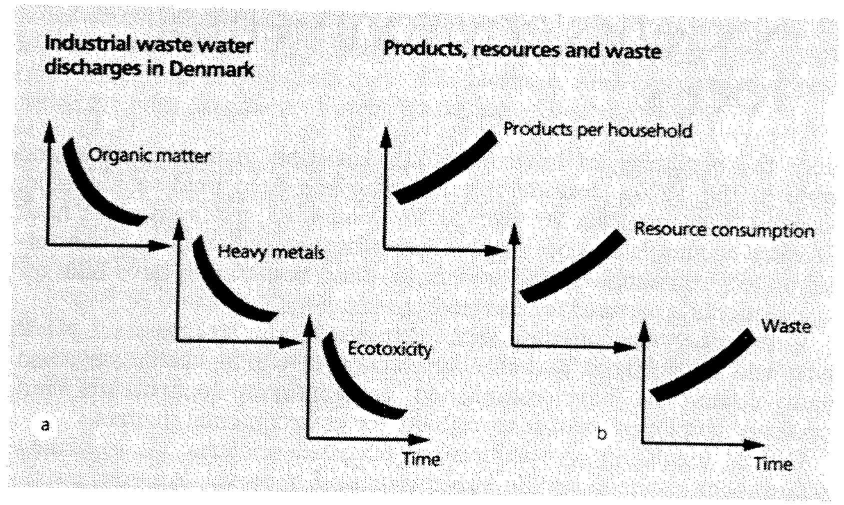


Figure 2.2a. Examples of the development in emissions of industrial waste water in Denmark over 10 years (Wenzel et al., 1990)

Figure 2.2b. Diagrammatic outline of the development in the quantity of products, resource consumption and quantities of waste over the same period

growing flow of products and the activities to which they are leading. It is the "many little streams which make the big river", and it is not possible to control environmental problems attributable to the flow of products by regulating the emissions from the manufacturing processes.

In recent years this recognition has influenced environmental administration, and the focus is changing from processes to products, so that attention is paid to the total impact from the entire product system. To a large extent, future environmental management will therefore occur at the interface between company and customer, as illustrated in Figure 2.3.

Through his or her choice of products, the consumer has a chance of influencing manufacturers toward reducing the environmental impacts of their products, by demanding environmentally friendly products, and the customer's attitude to the product's environmental characteristics therefore becomes a decisive factor. The role of the authorities in environmental regulation will change character, from direct management to a more indirect but no less important role, namely ensuring the right rules of play and parameters of competition in the market of the future,

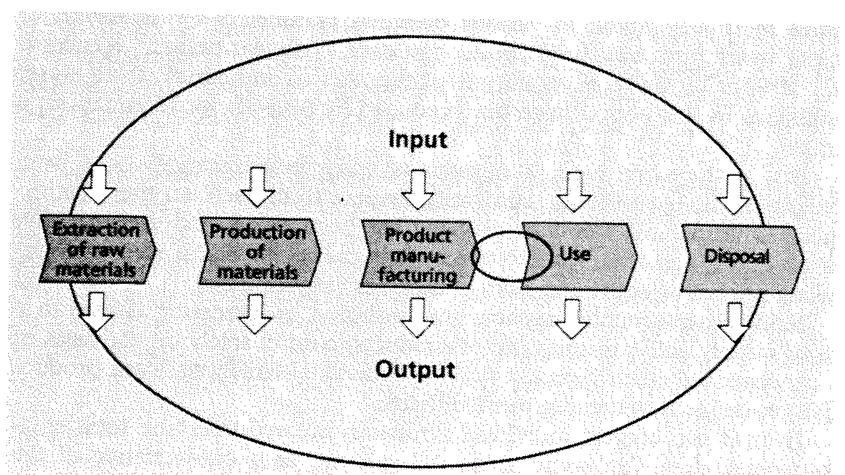


Figure 2.3. Future environmental focus in the industrialized world

including ensuring the reliability of the environmental information on the product.

Legislation and standardization

Environmental legislation in several countries has started to reflect the environmental focus on products and their product systems. Examples of actual and forthcoming initiatives in the area are shown in Figure 2.4. In 1995 the Dutch Ministry of the Environment published a memorandum on Dutch environmental policy in the product area, and Denmark has likewise published a proposal for a product-oriented environmental policy in 1996.

Among other initiatives in the area, Germany, Sweden and the Netherlands are preparing systems for the return of electronic waste, and the EU has adopted a packaging directive which prescribes environmental assessment of the packaging for its entire product system.

Standards for environmental management include formulations specifying that the environmental impacts of products should also be considered beyond the factory gates. The most important are BS7750, the EU system ECO-management and Audit Scheme (EMAS), and a forthcoming international standard in the ISO 14000 series. The reference list includes some of the standards noted.

Until now it has not been usual for companies to include the product's full product system in environmental management, but this is

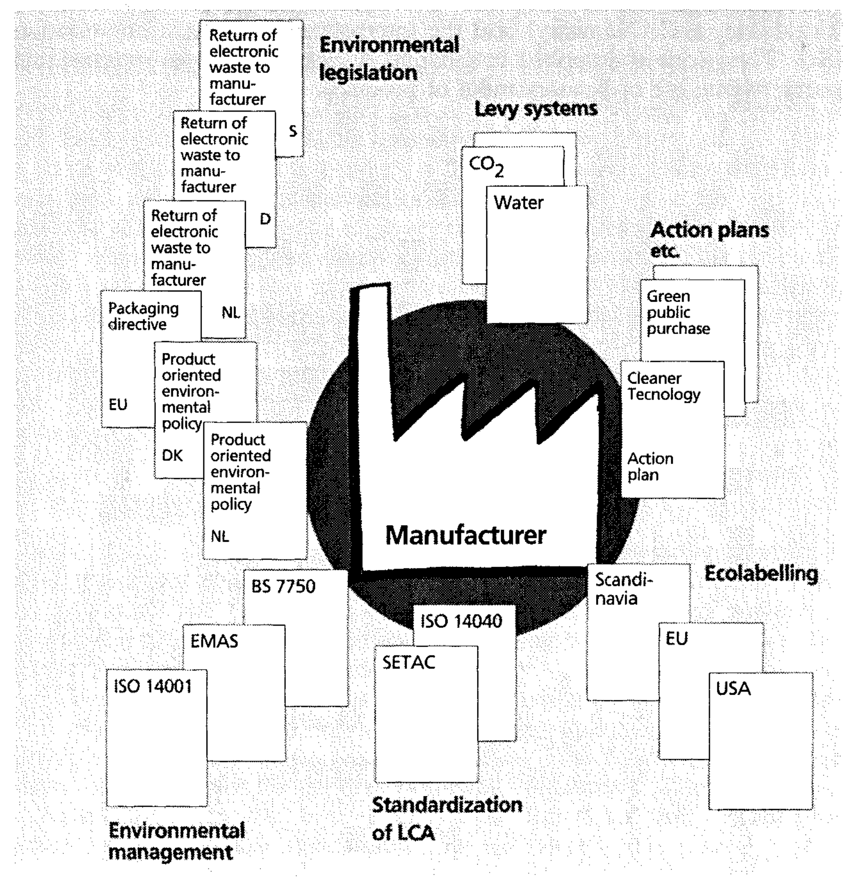


Figure 2.4. Examples of community initiatives of significance for a product-oriented environmental policy

expected to come. The Danish Ministry of the Environment and Energy and the Ministry of Commerce have established the Environmental Management Council, the duties of which include management of a subsidy system within the area of environmental management. Other Danish subsidy systems are already product-oriented, including the Ministry of the Environment and Energy's Action Plan for Cleaner Technology. Danish national authorities and institutional bodies must also consider the environment on an equal footing with other considerations in public purchases, and Danish counties and municipalities have been urged to do the same.

Within the EU, the Member States have adopted criteria for positive environmental labelling of products such as dishwashers and washing machines, toilet rolls and paper towelling, compost-based soil improvement agents, paint, laundry detergents and electric light bulbs. Work is proceeding on preparation of criteria for further product groups, including insulating materials, textiles, writing paper, refrigerators and hair spray. The criteria are based on an environmental assessment of typical product systems for the product type.

A number of environment-related taxes have been introduced in Denmark, but for the time being they are generally not directly related to the product. Examples include the tax on waste water discharge and the CO_2 tax.

Finally, work is proceeding internationally on standardization of the methods of environmental assessment of products, both within the environmental chemists' scientific society SETAC (Society of Environmental Toxicology and Chemistry) and the international standards organization ISO. This work is described in Chapter 4 together with an international status for the life cycle assessment of products.

3. Environmental assessment of products - what does it say?

The new environmental focus on the product is bringing environmental considerations closer to the source of the impact on the environment, namely the demand and the supply of products, and the competitive factors which drive them both. When the *product* is subjected to environmental assessment, environmental considerations can enter the chain of supply and demand and be a parameter of competition on an equal footing with the other parameters for the product such as price and quality. If both customers and manufacturers emphasize the product's environmental properties, environmental considerations can be included even before the product is made, and inappropriate solutions and technologies can be avoided from the start. The chain of suppliers and buyers often consists of many links, and if sound environmental properties are demanded, they will propagate along the whole chain and have a very great effect: see Figure 3.1.

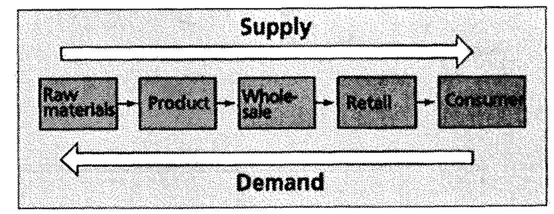


Figure 3.1. Simplified outline of the links in the chain of supply and demand

The product approach includes some major potentials for environmental improvements, which to date were used only to a limited extent and only for a few product types, e.g. organic foods, organic cotton and other products which have been assigned an environmental label.

The service provided by the product

A definition of a product is that it is of benefit to the user: it provides a service. If there is no definable user service, it is not a product. A consequence of focusing on the product is therefore making the product's *service* the focal point. The service, or the covering of the user's needs, is the reason for the product's existence, and it is therefore also the service which is ascribed all of the environmental impacts caused by the product.

But a service can be provided in many, often very different ways. The promise of environmental assessment of products is the possibility of comparing the environmental consequences of widely differing ways of providing a service, for it is thus possible to develop products and to select products on the basis of environmental considerations, and to achieve major environmental gains.

The functional unit

Figure 3.2 illustrates examples of various ways of providing a service. The object of the figure is to show how differently the same service can be provided. The tea can be stored in many different ways while it is drunk, the hair can be done in widely differing ways, and there are different ways of mowing the lawn.

To ensure that the different ways of providing a service are comparable, the service must be defined and precisely quantified. This is called determining a *functional unit* for the product. This functional unit is the fixed reference point for the environmental assessment. When alternative solutions are compared, everything but the functional unit can be permitted to vary, because the solutions are alternatives to one another only

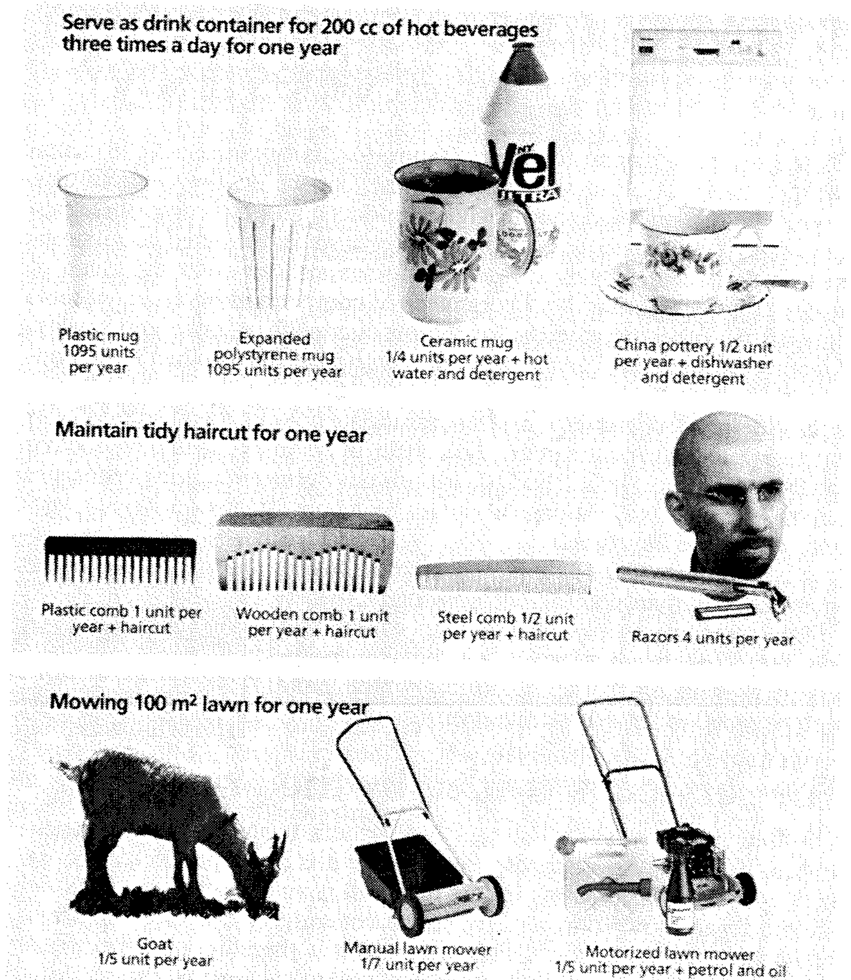


Figure 3.2. Different ways of providing the same service

when they provide the same service. Figure 3.2 describes the functional unit for the three services, and the different solutions are all specified as providing the functional unit which has been determined. Because of different life spans for the different types of products, a different number of products is used to provide the same functional unit. This is an important point in the environmental assessment of products.

Consider which solutions in Figure 3.2 are the most attractive environmentally.

Assessment of environmental impacts

The environmental assessment of products is a new discipline, but it builds on the experiences gained within the area of the environment over the last few decades. The method of assessment in the environmental assessment of products is especially bound to the principles developed within the environmental assessment of chemicals and mixtures of chemicals, as found, for example, in waste water emissions and industrial airborne emissions. These principles are well established, and they are described as an introduction to make it easier to explain the principle of the environmental assessment of products.

Environmental assessment of chemicals and mixtures of chemicals

The impact of a substance on the environment depends on three things, viz.

1) How much is emitted?
2) How hazardous is it?
3) In what quantities and concentrations does it reach those parts of the environment where it can exert its effect?

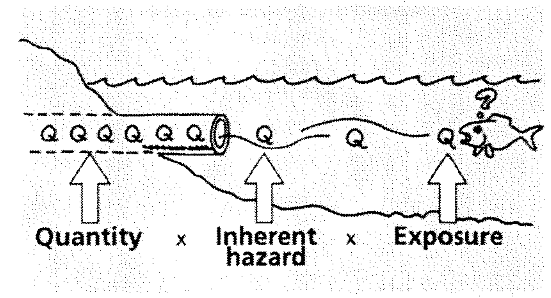


Figure 3.3. The impact of a chemical in the environment depends of three factors

This relationship is universal in the sense that it applies to emissions to air, water and ground, and that it applies to both individual chemicals and to mixtures of chemicals. Figure 3.3 illustrates the principle for emission of waste water. The relationship is expressed as:

Impact = quantity · impact potential · exposure

where the three factors in the expression represent the above three questions. The *impact potential* is the substance's inherent hazardousness, i.e. its ability to trigger a given impact. The exposure is the degree to which the substance reaches parts of the environment where the impact can be exerted, e.g. the degree to which a CFC emission reaches the ozone layer, or a toxic substance reaches an organism. This general relationship is well described in the literature; see, for example, Pedersen *et al.* (1994), who treat the assessment of waste water toxicity.

When the resulting environmental impacts of an emission are to be analysed, these three factors are often investigated separately, and the study of each factor has developed into independent professional environmental disciplines. A substantial knowledge is therefore available within each field, which can be used in the environmental assessment of products.

The question now is: what is involved in the environmental assessment of a product? How does this differ from the environmental assessment of an emission?

Environmental assessment of products

Figure 3.4 illustrates a product, an electric mixer. As it stands, it has no environmental impact, and in principle it can stand there for years without affecting the environment. The product in the figure only "has" an environmental impact by force of its past and its future.

The environmental impact of the product derives from the processes into which it enters. It is the processes which exchange substances or energy with the surroundings, and only if there is an exchange with the surroundings can there be an environmental impact.

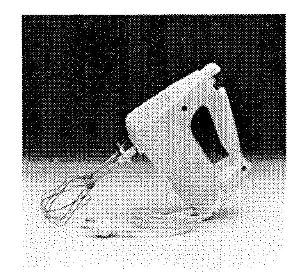


Figure 3.4. A product

The process's environmental exchanges

An *exchange* with the environment is defined as an *input* to a process, an *output* from the process, or an *internal interaction* with an operator (a worker) of the process. When, for example, the product is painted during manufacture, or when it uses energy when in operation, it enters into a process which has exchanges with the surroundings. Figure 3.5 illustrates the process's exchanges.

In general there is therefore only one way of making an environmental assessment of a product, and that is to assess the processes into which it enters. The task thus resembles the task already known, to carry out an

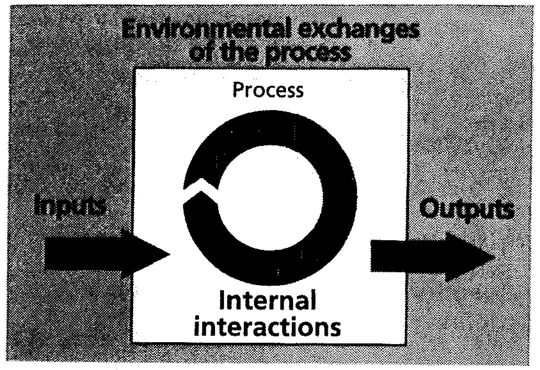


Figure 3.5. The process's environmental exchanges

environmental assessment of an emission. The product merely enters into numerous processes with many emissions which must be assessed together. In other words, numerous environmental assessments must be *put together*. The new element in the task is in this, and in assessing the many categories of impacts at the same time: various categories of resource consumption, environmental impacts and impacts on the working environment.

The task thus differs in the way that it is the whole and the overview which are important. Detailed knowledge of the individual emission must thus be dispensed with.

The product system

Even the simplest products enter into a large number of processes. The "life" of the product starts right from the first extraction of raw materials, and continues throughout manufacture, use and disposal of the product. The processes into which the product enters are collectively termed its *product system*.

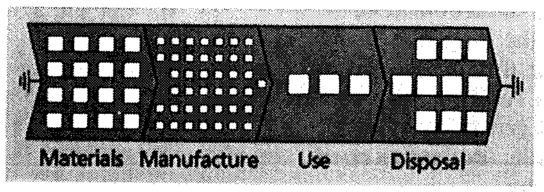


Figure 3.6. Conceptual outline of the product system

Figure 3.6 shows a conceptual outline of a product system. Four stages of the product's life are illustrated: 1) the material stage, 2) the manufacturing stage, 3) the use stage and 4) the disposal stage. A number of processes, which together comprise the stage, are shown in each stage.

The outline in Figure 3.6 shows what is understood by a product system, but it is not suitable for illustrating the extent and the variation within the product system.

The actual degree of detail is better given by the detailed model of the product system in Figure 3.7.

Figure 3.7 illustrates an additional dimension, namely geographic variation. In many cases, the same process will occur in several different places, and for products with a high proportion of exports this will apply in particular to the use and the disposal of the product. Processes in material production can also occur in several different places, because there are often different suppliers of the same product, and raw material extraction often occurs over large parts of the world.

The product system's main and lateral streams

Each of the small squares in Figure 3.7a symbolizes a process in the product's main stream, i.e. the stream of materials entering into the product. For almost all processes there are, however, a number of lateral streams associated with the process. The lateral streams are energy or ancillary substances, such as water, soap or solvents, which do not enter into the product but which are required for the process. Both energy and ancillary substances must be generated, and ancillary substances must often be disposed of after use, and they therefore have their own product systems before and after the process, as shown in Figure 3.7b. Environmentally, the main and the lateral streams can be equally significant, and as the point of departure, both are included in the product system.

Comparison of solutions

Figure 3.8 illustrates a brief version of the product systems for three of the solutions for the service "maintain tidy haircut for one year" from Figure 3.2, namely the three combs in different materials. These solutions are the most uniform of those shown in Figure 3.2, but their product systems and

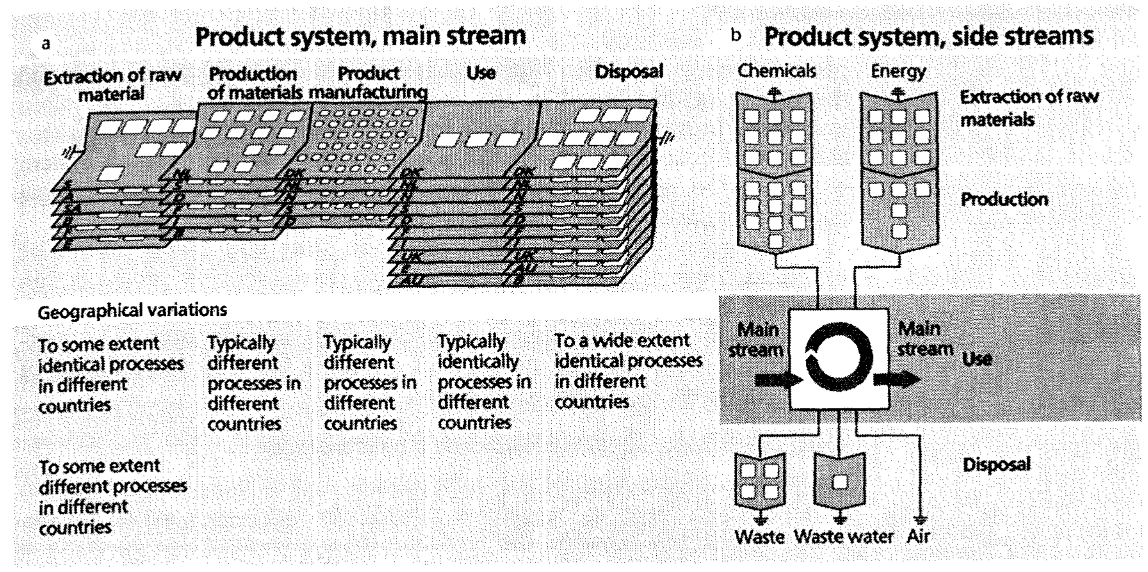


Figure 3.7. Detailed model of the product system, including main and lateral streams and geographic variation

therewith their potential environmental impacts are nevertheless very different.

Firstly, their life spans are different. The example assumes one plastic comb to provide the defined service, one wooden comb and half a steel comb. The first major differences lie here. Secondly, their product systems are very different in the first two stages, and in disposal, the materials have very different fates, and therewith different potential impacts in landfills and incineration and in nature.

Characteristics of the environmental assessment of products

Assessing the many processes in a product system can be a major task requiring large quantities of data. But it must still be possible to undertake an assessment within the time available for it. This shows that the nature of the task differs from that for the previously known assessment of an individual emission. The task is not to know all details and to assess each individual process and emission with great precision, but on the contrary to create an overview of the whole product system: an overview which has not previously existed.

Site-specific information

The large number of processes excludes the possibility of knowing all localities and site-specific conditions concerning the emissions in the

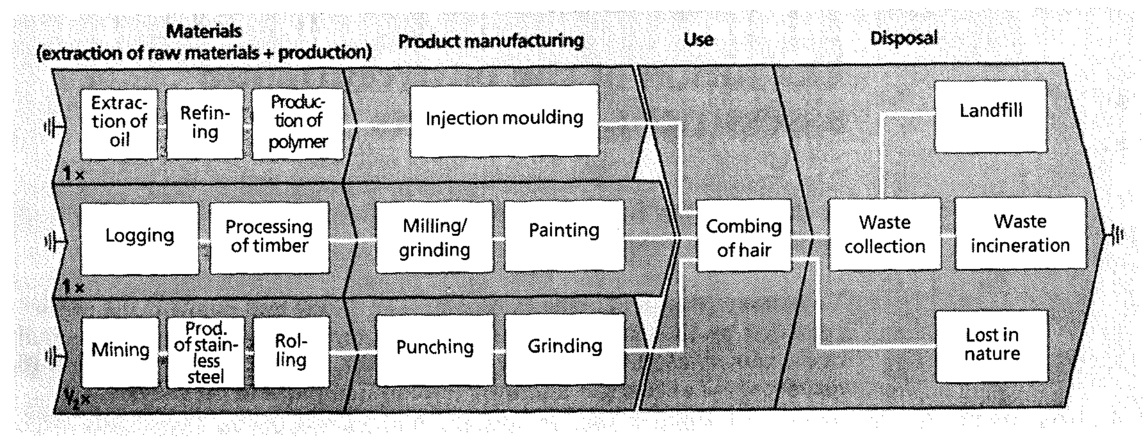


Figure 3.8. Simplified outline of the product system for three solutions for the service "maintain tidy haircut for one year"

product system. In other words, variation in the emission over time and the way it is distributed in the recipient following emission are often unknown. In most cases the need for large quantities of data means that the task of collecting data for all actual localities in the product system would be too great. Instead, generally available data for corresponding processes must be used to represent the actual processes.

Consequently, detailed information on time and place cannot be found in most cases. The environmental assessment of products can therefore most often not include an analysis of exposure, as described previously for individual emissions of chemicals and mixtures. The starting point is therefore that the product system is taken as independent of local conditions, as suggested in Figure 3.9.

The principle of environmental assessment

An analysis of exposure of the environment and its biota to an emission is required in order to be able to predict the emission's actual effects. When this is not possible, the environmental assessment of products is therefore limited to consideration of potential impacts or effects. The principle of the environmental assessment of products can therefore be summarized as:

ΣPotential impact = Σquantity of substance · substance's impact potential

summing all environmental exchanges in the product system. Depending entirely on where and how an exchange actually occurs, the potential impact can trigger real effects to a greater or lesser degree. In other words, depending entirely on the how the product system in Figure 3.9 is actually "landed", the effects which are triggered can be different.

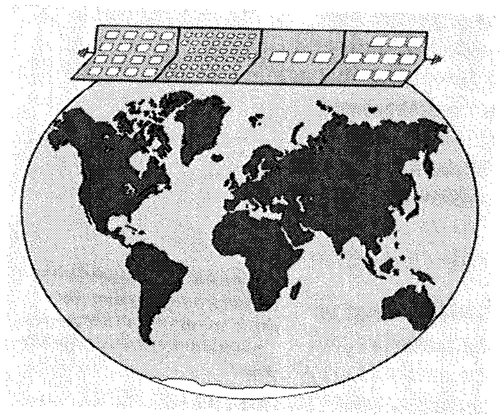


Figure 3.9. Initially, the product system is considered to be independent of specific local conditions

This feature of the environmental assessment of products is the most significant characteristic of the environmental assessment method. It is caused by the difficulty of generating data specific to the product in time and place, and it applies in general to all existing methods. Attention must be paid to this aspect so that results are not over-interpreted where in reality the conclusion is not unambiguous.

But this lack of accuracy in the environmental assessment is not a negative limitation. On the contrary, the accuracy in most cases is correct relative to the task of the assessment, namely to provide an overview and aid to ranking among solutions for a product which are very different in environmental terms.

Definition of the environmental assessment of products

The description of the environmental assessment and of the product and its product system can be summarized into the following definition of environmental assessment of products:

To assess a product environmentally is: to define and quantify the service provided by the product, to identify and to quantify the environmental exchanges caused by the way in which the service is provided, and to ascribe these exchanges and their potential impacts to the service.

4. Status of life cycle assessment

The generally recognized term for environmental assessment of products is *Life Cycle Assessment* or *LCA* in abbreviation. LCA is sometimes also read as life cycle *analysis*, but life cycle analysis is not a particularly good designation since an LCA always contains an element of *assessment*, namely the consideration and weighting of differing resource and environmental problems required to make a decision. The word *"analysis"* therefore signals too much objectivity. In German-speaking countries the terms *Bilanzierung, Ökobilanzierung, Umweltbilanzierung* or *Produktlinienanalyse* are often used, and in French-speaking countries the word is *ecobilan*.

This book uses only the term "life cycle assessment" or "LCA", with "environmental assessment of products" as an occasional synonym.

Historical development

The first examples of environmental assessments of products were carried out on packaging and published at the end of the 1960s and the beginning of the 1970s in the USA. They were called "Resource and Environmental Profile Analyses" (REPAs) and focused primarily on energy consumption, resource consumption and generation of waste, in accordance with the focus in the environmental debate of the time. At that time there was still too little knowledge on processes' emission of environmentally hazardous substances and their possible impacts on the environment to permit assessment of a potential environmental impact (see, for example, Hunt *et al.*, 1974).

At the beginning of the 1980s, interest in the environmental assessment of products grew in connection with discussions on environmental impacts from various forms of packaging, and LCAs were used in several European countries to compare different beverage packagings (BUS, 1984; Lundholm & Sundström, 1985; Franke, 1984). Obtaining unambiguous results and conclusions proved to be difficult in some cases, because the database and the methods varied in the different studies. This was unsatisfactory, and it was one of the reasons why a more systematic development of the methodological basis for the life cycle assessment of products began.

From the end of the 1980s to today (1997), interest in life cycle assessment has grown very strongly, and a growing number of different and increasingly complex products and systems have been assessed. Summaries are given in Pedersen & Christiansen (1992) and "Sustainability" (1993). Different interests in society have seen a major perspective in this development of the environmental focus and they have each commenced work from their own point of view. The authorities use life cycle assessments, for example, in work on environmental action plans and in environmental labelling of products. Companies use them in product development, environmental management and marketing, and consumer organizations use them in counselling consumers.

Accompanying the growing activity within the field of life cycle assessment, more attention has been paid to the development of a methodological basis. The international scientific society of environmental chemists, SETAC (Society of Environmental Toxicology and Chemistry) started work on life cycle assessments in 1990, and within a few years it became the international forum for discussion of the methodological basis of the LCA.

Table 4.1 provides an overview of some of the most important international conferences and workshops which have been held since 1990 with life cycle assessment as their theme. SETAC's dominant position is clear from the table, which also illustrates how the items have changed from the general to the more specialized aspects of the life cycle assessment method.

The object of the SETAC workshop in 1993 in Sesimbra, Portugal, was to attempt to set common guidelines for the carrying out of an LCA, and the report from this workshop, "Guidelines for Life-Cycle Assessment: A Code of Practice", has gained the status of a common reference for life cycle assessment (Consoli *et al.*, 1993).

Table 4.1. Workshops and conferences held since 1990 on subjects related to life cycle assessment (Christiansen et al., 1995, and other sources)

Venue	Time	Organizer	Topic
Washington, DC, USA	May 90	WWF	LCA, in general
Vermont, USA	August 90	SETAC	LCA, in general
Leuven, Belgium	September 90	Procter & Gamble	LCA, in general
Leiden, Netherlands	December 90	SETAC	Methodological background
Sandestin, USA	February 92	SETAC	LCA, impact assessment
Washington, DC, USA	March 92	SETAC	
Potsdam, Germany	June 92	SETAC	LCA, impact assessment
Wintergreen, USA	October 92	SETAC	Data quality
Lyngby, Denmark	January 93	TUD	Assessment of ecotoxicity
Sesimbra, Portugal	April 93	SETAC	Guidelines of LCA
Amsterdam, Netherlands	June 93	UNEP	Applications of LCA
Brussels, Belgium	December 93	SETAC	Case studies
Leiden, Netherlands	February 94	SETAC	Allocation
Brussels, Belgium	April 94	SETAC	Impact assessment
Zurich, Switzerland	June 94	SETAC	Impact assessment
Copenhagen, Denmark	October 94	Nordic Council of Ministers	Guidelines of LCA
Brussels, Belgium	December 94	SETAC	Case studies
Florida, USA	February 95	SETAC	Index and ranking systems
Hankø, Norway	March 95	WBCSD, NEP project	Improvement assessment and applications of the LCA tool
Copenhagen, Denmark	June 95	SETAC	LCA impact assessment and toxic emissions LCA in ecolabelling
Stockholm, Sweden	September 95	IVL	Waste treatment processes in LCA
Brussels, Belgium	December 95	SETAC	Case studies

WWF:	WorldWide Fund for Nature
SETAC:	Society of Environmental Toxicology and Chemistry
Procter & Gamble:	The Procter & Gamble Company
TUD:	Technical University of Denmark
UNEP:	United Nations Environment Program
WBCSD:	World Business Council for Sustainable Development
NEP:	Nordic Project for Environmentally-Oriented Product Development
IVL:	Institut för Vatten och Luftvårdsforskning

Status of the method

Table 4.2 shows the status of the methodological development in the various phases and elements in the life cycle assessment, as described in SETAC's "Code of Practice". It is clear that most phases and elements have been determined at the conceptual level, but only the introductory components have been determined operationally.

After the Sesimbra workshop in 1993, SETAC established a number of different working groups to continue work on those parts of the methodological basis which were not yet determined operationally. Most progress has been made within the scope definition phase, where agreement has been approached on a common framework for several of the elements.

The EDIP method represents an operationally determined method which covers all phases, but there have also been earlier attempts to present detailed guidelines for the carrying out of a life cycle assessment along the lines presented in this book. The most important included:

Methodological state-of-the-art according to "Code of Practice" from SETAC

LCA phases and elements	Status
Goal definition	(✓)
Scope definition	
- Functional unit	(✓)
- Choice of assessment criteria	✓
- Time scope	(✓)
- Technological scope	(✓)
- Scope definition of the product system	✓
- Allocation	(✓)
Inventory	✓
Impact assessment	
- Impact potentials (classification and characterization)	(✓)
Global environmental impacts	✓
Regional and local impacts	+
- Normalization	(✓)
- Weighting	(✓)

Legend
✓: Operationally specified
(✓): Conceptually specified
+: Not specified

Table 4.2. Status of the life cycle assessment method's components in SETAC's "Code of Practice" (Consoli et al., 1993)

- The Swiss *Ökopunkte* ("Ecopoints") method, which presented one of the first comprehensive assessment methods for use in the LCA (Ahbe *et al.*, 1990).
- The CML method, a Dutch method from the University of Leiden which is often quoted in the international LCA literature, especially for its detailed treatment of the impact assessment phase (Heijungs, 1992).
- Detailed recommendations on the procedure for preparation of inventories for the product system published by the US EPA (US EPA, 1992).
- Guidelines prepared by a group consisting of Scandinavian researchers and consultants within product life cycle assessment (Lindfors *et al.*, 1995).
- The EPS method for life cycle assessment, which is specially oriented towards inclusion of environmental considerations in product development (Ryding, 1995).

Standardization

Work has been continuing since 1993 within the International Organization for Standardization (ISO) on development of international standards for life cycle assessment. A general standard for the LCA area with ISO number 14040 is expected to be finally adopted during 1997. Work is also proceeding on three more detailed standards for the different phases of the LCA:

- one for goal definition, scope definition and inventory analysis,
- one for impact assessment,
- one for interpretation.

The first of these standards will be presented for voting in 1997, the remaining two presumably later.

In May 1995 the European standards organization CEN (Comité Europeén de Normalisation) adopted a so-called CEN report, which, in contrast to a CEN standard, is for guidance only, with recommendations for the elaboration of life cycle inventories for packaging systems.

Work in both the ISO and the CEN is influenced by the fact that life cycle assessment is still a very young discipline, and that in many areas a common perception of how the task is to be carried out has therefore not yet been developed. This is also apparent in Table 4.2.

Applications of LCA

Table 4.3 gives an overview of the contexts in which life cycle assessments are used today (1997).

It is important to be conscious of the goal of the LCA. Even if there are general principles for the LCA, the concrete design of the assessment depends on the application and the type of decision it is intended to support. This is illustrated in Table 4.4, which provides some examples of how the use of an LCA makes different demands on the method with respect to the time over which the result will apply.

Table 4.3. Uses of environmental assessment of products in Denmark, 1996

Active party	Application	Example
Authorities	Community action plans	■ Incineration versus recycling of paper ■ Recyclable glass bottles versus other beverage containers ■ Ranking of industrial products
	Environmentally conscious public purchase	Cars, work clothes, canteen service, office furniture
	Consumer information	Ecolabel
Company	Establish environmental focus	■ Identification of areas of improvement ■ Product-oriented environmental policy ■ Environmental management
	Design choices	■ Choice of concept ■ Choice of component ■ Choice of material ■ Choice of process
	Environmental documentation	Environmental information to costumers
Consumer organizations and other associations of interested parties	Guidance to environmentally conscious consumption	Ecolabel
	Life cycle assessment of community actions	Ecological or conventional farming, transport systems

If, for example, the life cycle assessment is used as the basis for environmental labelling of products, it must provide an actual picture of the product type's current environmental impact. For EU environmental labels the results only have to apply for three years, since EU environmental labelling criteria are to be revised at least every third year.

If, on the other hand, it is used as a part of the basis on which decisions are made in product development, the results must in principle be valid for the entire time during which the product is expected to be in production, plus the product's life span after production ceases.

Table 4.4. Periods of validity for results in various applications of environmental assessments of products

Objective	Application	Support for decision	Time horizon T
Focus	Product development	Background for environmental specifications, design strategies, principles and rules	$3 < T < 3 + P + L$
	Eco labelling	Identifies important environmental properties for the product category	$0 < T < 3$
	Community action plans	Identifies environmentally important product groups	$0 < T < L$
Choice	Product development	Ongoing identification of the best choices from alternative solutions	$2 < T < 2 + P + L$
	Cleaner technology	Identifies the best available technology by means of LCA	$1 < T < 1 + L$
	Community action plans	Identifies the best community strategy for a certain problem or product	$0 < T < 5$
	Consumer information	Documents potential environmental impacts from a certain product	$0 < T < 1$

Legend
T = Time horizon for which the decision must be valid (examples)
P = Period of time during which the product is produced
L = Lifetime of the product

5. Environmental assessment and product development

The development of new products is a creative process and as such difficult to characterize within a fixed framework. But the process has some basic aspects which should be understood when environmental considerations are to be integrated and the environmental assessment method adapted to product development. Some of the aspects in product development which are most important for the practitioner of the environmental assessment are therefore described here.

The task of the designer

Some of the most important tasks of the designer is to create and to choose among solutions. When a business opportunity is recognized and the goals are determined, the designer must find a solution which fulfils the goals.

The goals for the product create demands on functions in the product: firstly, demands on the general service functions, followed gradually by demands on sub-functions in the product as its concept, structure and details are determined. This is illustrated in Figure 5.1.

The figure illustrates in simplified form some of the decision making processes in the development of two very different products, namely a ship and a refrigerator. The object of the figure is to show how the product is born as a result of a number of decisions from the general concept to the individual detail, and where in this decision making process the most significant environmentally decisions are made.

The example of development of a ship to fulfil the general function "transport between Denmark and Sweden" is not a typical product development project, but in a simple manner it illustrates the significance of the various levels in the decision making process. At the top level there are several conceptually different ways of providing the service: ship, bridge, tunnel, aeroplane ..., and in principle there is an unlimited number of solutions. The choice of "ship" gives rise to a number of other functional demands: create the ability to float, maintain course, change course, create forward motion ..., and the choice of "wind" as a means of creating forward motion gives rise to demands for new functions, and so on. The choices at each level very strongly narrow the space within which decisions can be made, and the framework for the product's environmental characteristics is narrowed at each level. Consider where the most environmentally significant decisions lie. Intuitively, it appears that the choice between ship, bridge, tunnel and aeroplane is very significant, as is the choice between wind, sun, oil and uranium as propellant. The choices at the top level thus appear to mean more in environmental terms than the choices at the bottom levels, e.g. choice of material for the mast and chemicals for protecting it against the weather.

The example of development of a refrigerator is more typical for product development in a company. The figure illustrates several branches in the decision making structure, but still only a small portion of the functions determined in the refrigerator. The most significant choice at the concept level appears intuitively to be the choice of refrigeration system, i.e. the choice of electric heat pump relative to, for example,

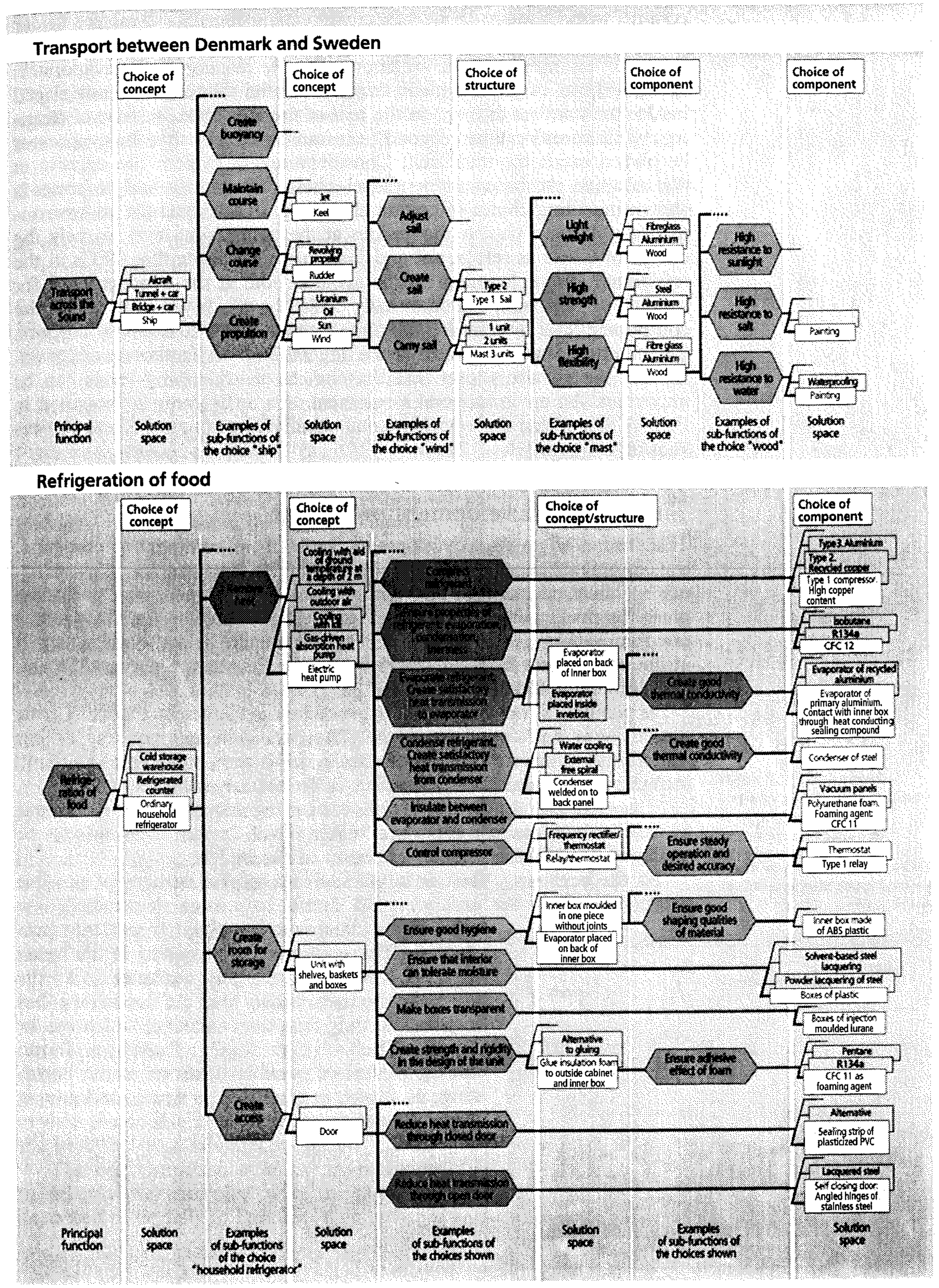


Figure 5.1. Solution space and choices in product development. Some of the choices made are shown in white. Some of the functional demands caused by the choices are shown in dark grey

cooling with outdoor air in winter or placing the unit 2 metres under ground level to make use of the permanent cold there. At the structural level, for example, choices are shown for the placing of the evaporator: considerations of good hygiene require that the evaporator is not placed inside the unit, but directly on the rear of the inner box for ease of cleaning, while considerations of good heat transfer require that the evaporator be placed inside the unit itself. Considerations of hygiene are decisive in this example. At the component level, choice of materials and processes is shown including choice of certain chemicals. In this example an environmentally decisive choice also resides at the component level, namely the choice of CFCs as refrigerant and foaming agent. Note that CFCs in the refrigerant and/or foaming can be avoided both at the concept level, for example by choosing a geothermally cooled or gas-driven unit, and at the component level by selecting alternative chemicals. The example supports the judgment that the choices at the general level are environmentally significant, but it also shows that the choices at underlying levels can be important. An environmental assessment of a refrigerator is presented in Part V, illustrating the environmental significance of many of the choices shown in Figure 5.1.

The product development procedure

The course of product development varies from company to company, but some basic aspects are common. When the first idea for a new product is conceived, the idea and the business basis are analysed, and some goals for the product are set up. The general concepts for the product are then determined, followed later by the details. In some cases, details at the component level are determined from the start, e.g. "build in aluminium" or "build without CFCs".

A picture of the development procedure is shown in Figure 5.2, by the arrow at the top of the figure. The procedure can be more or less formalized or detailed, but in the main, most companies will be able to recognize their product development in the sequence shown.

The object of the figure is to show how the decisions over the course of development narrow the space within which further decisions can be made, as described in the two examples in Figure 5.1.

At the beginning, there is in principle an infinite number of possible solutions, and at the end, when all details have been determined, one solution has been chosen which is put into production. The solutions are illustrated in the figure as product systems with grey contours under the curve. In the early phases they are not known, but in principle they exist as possibilities which can be found. The solution finally chosen is found among the many possible solutions at the beginning, as shown in black in the figure, and among these the environmentally best solution is also to be found.

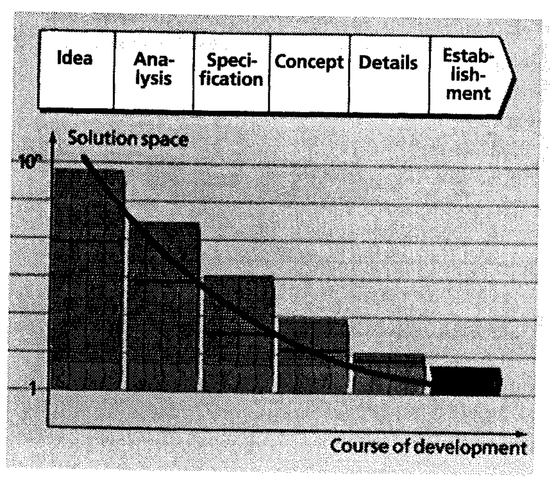


Figure 5.2. Narrowing of the solution space during product development

Basic requirements for the environmental assessment method

The aspects of product development shown in Figure 5.2 make some significant demands on the method of environmental assessment and on how it is used in product development. Two pivotal requirements are:

- the designer's decisions must be able to be supported early in the course of development,
- the degree of detail in the environmental assessment must be adapted to its purpose in product development.

The requirement for early support of the decisions

As the environmentally most significant decisions are most probably made in the earliest phases of product development, the environmental assessment must be able to support these decisions.

Environmentally attractive product systems and solutions in the product must be able to be identified as early in the product development as possible, so that environmental considerations can be included in the most significant decisions.

This requirement is met in the EDIP method, basically by its building on the use of reference products to represent the new product. With the aid of the reference products, the largest part of the new product system is predicted, and in this way, points of focus can be designated and goals set for the new product from the very beginning of product development. This is described in more detail in Part II.

Requirements concerning the level of detail

The actual product system for the new product is not known during product development, i.e. the variation in time and place for the product system's processes and their environmental exchanges is not known.

The closer product development comes to the establishment and operation phases, the closer the product system is to being identified. Only in the operation phase is it fully known where the processes are occurring. This is illustrated in Figure 5.3. In product development it is therefore necessary to work without full knowledge of variations in time and place, but with probabilities. This lack of knowledge about the processes' variation in time and place in product development agrees entirely with the degree of detail in the information base for environmental assessment of products. The *probabilities* in product development correspond to the *potentials* in the environmental assessment.

The environmental tasks in product development and the interplay with the designer are described more fully in Part III.

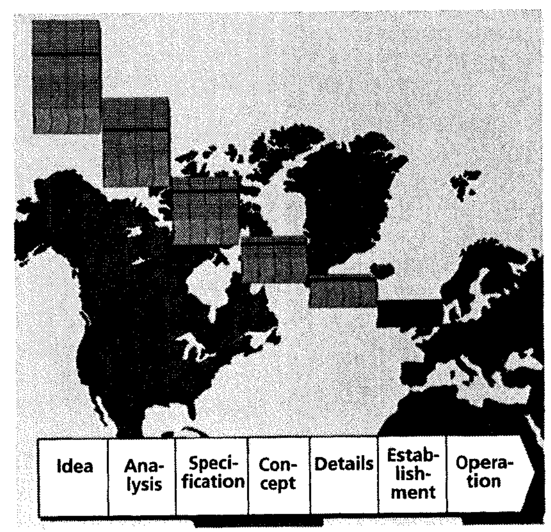


Figure 5.3. The product system's placing and variation in time and place are unknown during product development