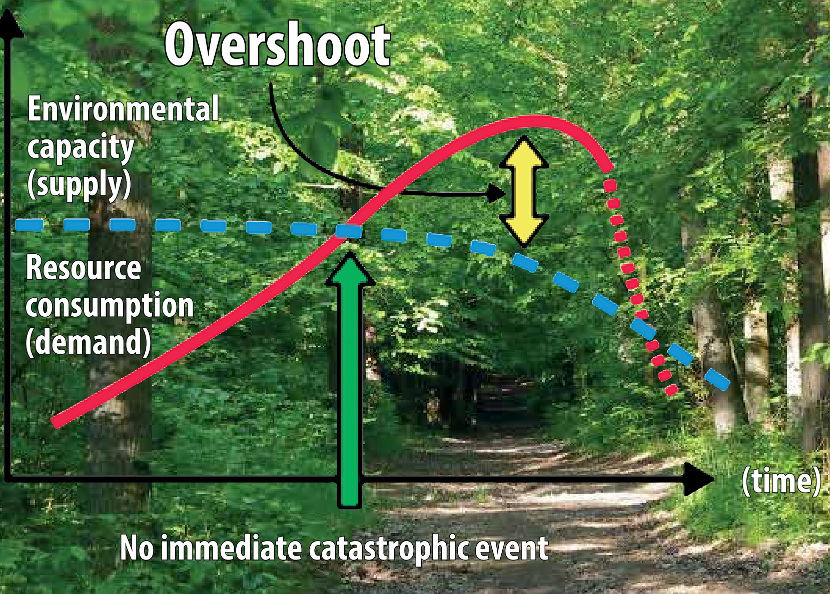
UZWATER

Sustainable Use and Management of Natural Resources



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Book Contents Overview

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1

Human Development and Basic Resource Theory

Chapter 1
A history of human societies, resource use and (un)sustainable development

1.1 Something new under the Sun

Sustainable development is about how we – humanity – can live on the resources that our planet provides for us. Therefore the study and understanding of resource flow and resource use and management is the core of sustainability science. Our resource consumption has increased over the entire history of mankind, but the planet is the same, not any bigger. How can we as humanity adjust to the resources available to us?

The American historian John McNeill undertook to write a global environmental history for the 20th century. He started assuming that the environmentalists were exaggerating. Yes, there were environmental problems, but there has always been. "Nothing new under the sun" he told them when he started his project. But when he published he had changed his opinion and the title of the book became "Something new under the Sun". Not surprising! During the 20th century the human population had increased 4-fold, from about 1.5 billion to 6 billion. In addition, the economy per capita had also increased 4-fold. Thus the resource use on the planet had increased about 16-fold during 100 years. Obviously it cannot go on like that.

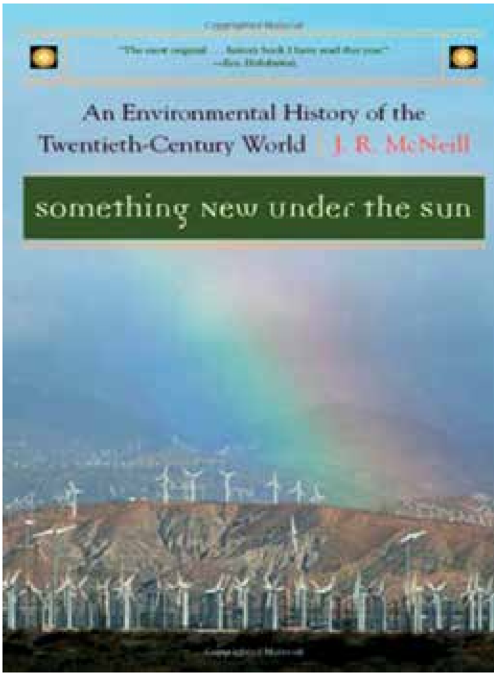

Figure 1.1. Something New Under the Sun, John McNeill, 2001.

He examined a series of resources and the result was similar (Table 1.1): Global economy increased 14 times, industrial production 40 times, that is per capita income increased about 4 times. It is also noteworthy that energy use increased about as the economy, which is explained by the fact that economy is tightly coupled to energy for countries which are still developing. Emission are also tightly coupled to energy use since ener-

Table 1.1. Global Development 1900 – 2000 (Source: John McNeill, Nothing new under the sun, 2001).

global population	increased	4x
global economy	increased	14x
industrial production	increased	40x
energy use	increased	16x
carbon dioxide emissions	increased	17x
sulphur dioxide emissions	increased	13x
ocean fishing catches	increased	35x
number of pigs (=meat eating!)	increased	9x
forests	decreased	20 %
agricultural fields	increased	2x
Blue whale	decreased to 0.25 %	

gy use is completely dominated by fossils and thus causes much of the emissions. Here carbon dioxide, CO_2, and SO_x is mentioned but it is also possible to mention NO_x or Hg, mercury. As people get a little richer they increase meat eating, reflected in the number of pigs, in this period about 2-fold, which is also a pressure on our environment and requires more resources. We can also see that the production from the environment is increasing and fields have expanded and forests shrink.

In Western Europe and the USA the strongest resource growth was after WWII, roughly between 1955 and 1975. During less than one generation resource consumption increased almost 3-4 fold for very many products: metals, fertilisers, fossil fuels etc. During this period our societies went from fairly sustainable to affluent societies, affluent meaning with a large resource flow.

The change was much faster in the end of the century than in the beginning. In fact increase was most often measured in percent of previous year! If this percentage growth is constant we have exponential growth! This means constant doubling time. This gets very soon out of hand. Exponential growth may be illustrated by anything from the number of McDonald restaurants in the world to the consumption of paper.

It is also during this period that the landfills (garbage piles) of Europe increased tremendously! Around 1980 concern grew about what to do with the mountains of household waste. This was due to an increasing linear resource flow. The resources went from extraction to production, consumption and waste in a straight line! It is simply a recipe for resource wasting! To make this more sustainable we need to have cyclic resource flow. Recycling is an important part of sustainable development.

1.2 The great acceleration

When the rapid changes of the last years are seen in a larger perspective sustainability researchers often focus on the last 300 years, that is, from the early onset of industrialisation up to today. This is when extraction of resources, especially fossil fuels, coal oil and gas, is increasing – first slowly then dramatically – as is the consequences of the resource use, environmental impacts of all kinds. This includes emissions of carbon dioxide but many other emission, as well as the great changes in the landscape of the planet. It is also the period when population growth is exploding as health and child survival increases when medical care improves.

As development is speeding up at increasing rates in the entire period it is called *The great acceleration*. This term was first used by Australian scientist Will Steffen, who together with John McNeill and the Dutch chemist and Nobel laureate Paul Crutzen developed the concept in an Ambio article in 2007. The following text is an extract from their article:

"One of the three or four most decisive transitions in the history of humankind, potentially of similar importance in the history of the Earth itself, was the onset of industrialization. In the footsteps of the Enlightenment, the transition began in the 1700s in England and the Low Countries for reasons that remain in dispute among historians. Some emphasize material factors such as wood shortages and abundant water power and coal in England, while others point to social and political structures that rewarded risk-taking and innovation, matters connected

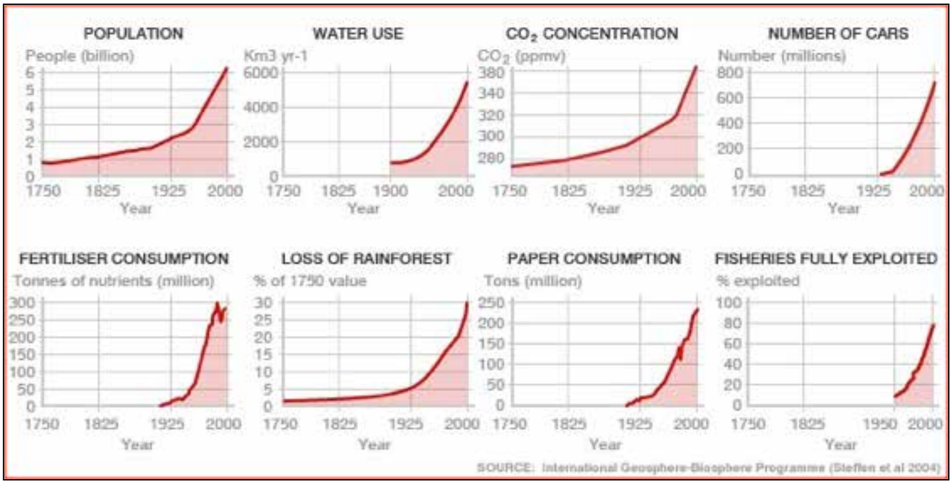

Figure 1.2. Exponential growth in a number of parameters illustrates the sharply increased use of resources (Source: Limits to Growth 30 year update, Meadows et al.:)

to legal regimes, a nascent banking system, and a market culture. Whatever its origins, the transition took off quickly and by 1850 had transformed England and was beginning to transform much of the rest of the world.

What made industrialization central for the Earth System was the enormous expansion in the use of fossil fuels, first coal and then oil and gas as well. Hitherto humankind had relied on energy captured from ongoing flows in the form of wind, water, plants, and animals, and from the 100- or 200-year stocks held in trees. Fossil fuel use offered access to carbon stored from millions of years of photosynthesis: a massive energy subsidy from the deep past to modern society, upon which a great deal of our modern wealth depends. Industrial societies as a rule use four or five times as much energy as did agrarian ones, which in turn used three or four times as much as did hunting and gathering societies. Without this transition to a high-energy society it is inconceivable that global population could have risen from a billion around 1820 to more than six billion today, or that perhaps one billion of the more fortunate among us could lead lives of comfort unknown to any but kings and courtiers in centuries past.

Fossil fuels and their associated technologies – steam engines, internal combustion engines – made many new activities possible and old ones more efficient. For example, with abundant energy it proved possible to synthesize ammonia from atmospheric nitrogen, in effect to make fertilizer out of air, a process pioneered by the German chemist Fritz Haber early in the 20th century. The Haber-Bosch synthesis, as it would become known (Carl Bosch was an industrialist) revolutionized agriculture and sharply increased crop yields all over the world, which, together with vastly improved medical provisions, made possible the surge in human population growth.

The imprint on the global environment of the industrial era was, in retrospect, clearly evident by the early to mid-20th century. Deforestation and conversion to agriculture were extensive in the mid latitudes, particularly in the northern hemisphere. Only about 10% of the global terrestrial surface had been "domesticated" at the beginning of the industrial era around 1800, but this figure rose significantly to about 25–30% by 1950. Human transformation of the hydrological cycle was also evident in the accelerating number of large dams, particularly in Europe and North America. The flux of nitrogen compounds through the coastal zone had increased over 10-fold since 1800.

The global-scale transformation of the environment by industrialization was, however, nowhere more evident than in the atmosphere. The concentrations of CH_4 and nitrous oxide (N_2O) had risen by 1950 to about 1250 and 288 ppbv (parts per billion by volume), respectively, noticeably above their preindustrial

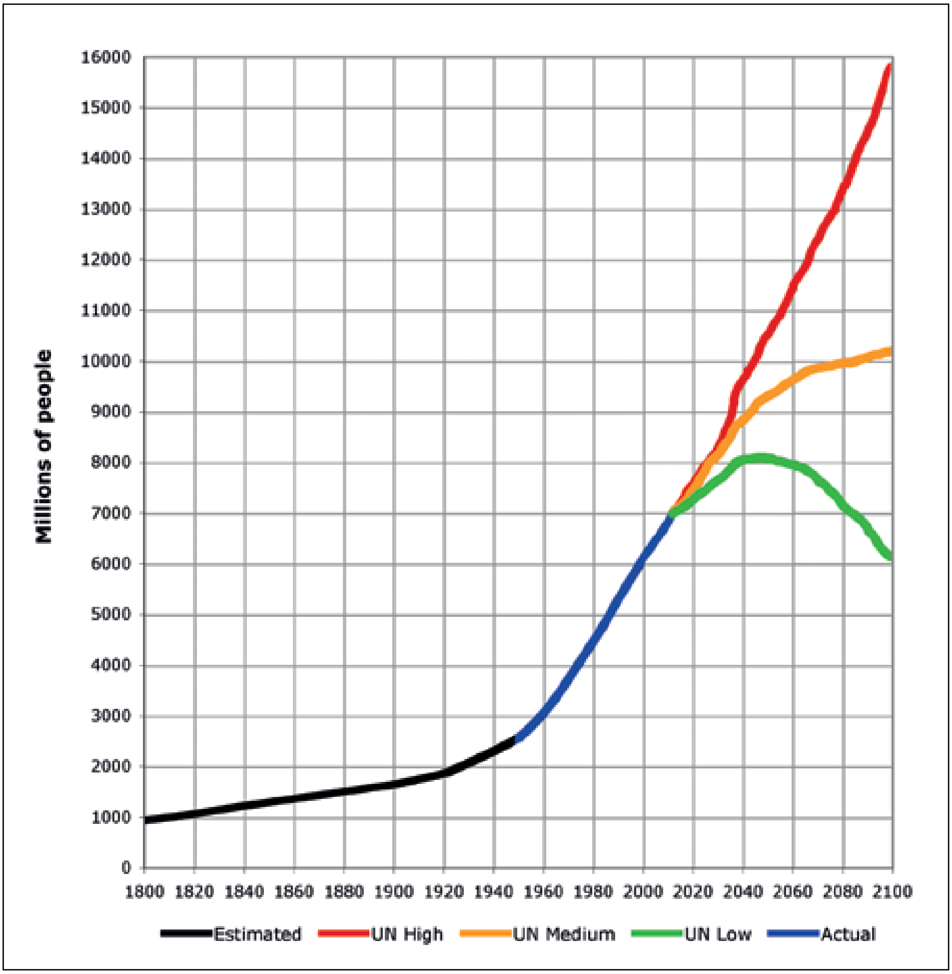

Figure 1.3. Global population growth (Source: http://en.wikipedia.org/wiki/World_population#/media/File:World-Population-1800-2100.svg).

values of about 850 and 272 ppbv. By 1950 the atmospheric CO_2 concentration had pushed above 300 ppmv (parts per million by volume), above its preindustrial value of 270–275 ppmv, and was beginning to accelerate sharply.

The human enterprise suddenly accelerated after the end of the Second World War. Population doubled in just 50 years, to over 6 billion by the end of the 20th century, but the global economy increased by more than 15-fold. Petroleum consumption has grown by a factor of 3.5 since 1960, and the number of motor vehicles increased dramatically from about 40 million at the end of the War to nearly 700 million by 1996. From 1950 to 2000 the percentage of the world's population living in urban areas grew from 30 to 50% and continues to grow strongly. The interconnectedness of cultures is increasing rapidly with the explosion in electronic communication, international travel and the globalization of economies. The pressure on the global environment from this burgeoning human enterprise is intensifying sharply. Over the past 50 years, humans have changed the world's ecosystems more rapidly and extensively than in any other comparable period in human history. The Earth is in its sixth great extinction event, with rates of species loss growing rapidly for both terrestrial and marine ecosystems. The atmospheric concentrations of several important greenhouse gases have increased substantially, and the Earth is warming rapidly. More nitrogen is now converted from the atmosphere into reactive forms by fertilizer production and fossil fuel combustion than by all of the natural processes in terrestrial ecosystems put together. The remarkable explosion of the human enterprise from the mid-20th century, and the associated global-scale impacts on many aspects of Earth System functioning, mark the second stage of the Anthropocene – *the Great Acceleratio*n.

Underlying global change are human-driven alterations of

i) the biological fabric of the Earth;
ii) the stocks and flows of major elements in the planetary machinery such as nitrogen, carbon, phosphorus, and silicon; and
iii) the energy balance at the Earth's surface.

The Great Acceleration took place in an intellectual, cultural, political, and legal context in which the growing impacts upon the Earth System counted for very little in the calculations and decisions made in the world's ministries, boardrooms, laboratories, farmhouses, village huts, and, for that matter, bedrooms. This context was not new, but it too was a necessary condition for the Great Acceleration."

1.3 The first resource crisis

If the first consequence of large resource use is the environmental pollution caused by the waste created, the other side of accelerated resource use is that limited resources are depleted, used up.

Overhunting and overfishing is well known. In Europe the large mammals were repeatedly over-hunted and simply disappeared from large areas, much of this happened already thousands of years ago. The last species of the European megafauna, the European Bison, was close to extinction in the 1920s when it was saved by Polish scientists in the very last moment and continued to room in the large forests between Poland and Belarus. The large populations of salmon – so enormous that its extinction was out of questions – disappeared from many Norwegian and Swedish rivers hundred years ago. Then not only over-fishing but also acid rain from European industry was part of the cause. The grey seal in the Baltic Sea similarly was almost extinct around 1950, when chemical pollution almost gave it the last blow. The seal was saved by environmental legislation and nature protection and is since the 1990s back in safe numbers.

More recently the decrease of oil, coal and gas have been in focus. Everyone agrees that these non-renewable resources will at some point be depleted. There will be a maximum of oil production, the so called *peak oil*, and then a decrease. This peak seem to be happening right now. In a similar way we talk about peak coal, peak gas and peak phosphorus.

Figure 1.4. The channelized stove. After experimentation in a mansion just outside Västerås, Sweden, Cronstedt together with the General Fabian Wrede introduced in 1767 the "kakelugn" a channelized stove. It dramatically reduced the amount of wood needed for heating.

Forests has been a critical resource in almost all human societies. Forests have a key role in sustainable development. The most typical single character of collapsed societies is the loss of their forest. The most telling example may be *Easter Island* in the middle of the Pacific Ocean, where a once vivid society after destruction of the forests only could house a small and desperate population in a barren landscape. The story has been told repeatedly, but a most convincing version is in the book *Collapse* by Jarred Diamond. In his book Diamond analyses a dozen societies which collapsed, all of them characterized by the loss of forest resources.

Forests in Europe today are increasing; the forested area reached a minimum around the beginning of the 20th century, when agriculture expanded to use also less profitable, previously forested land; much of this has later been reforested. There was, however, a previous deforestation crisis in Europe, which occurred in the beginning and mid of the 1700s. Large area of forests was then almost clear-cut, due to the large demand for timber, mostly in the mining industry. In Saxony (today a state, *bundesland*, in Germany, then a kingdom) timber was used in the silver mines for building shafts and heating the ore. Carl von Carlowitz, head of the Royal mining office in the Kingdom of Saxony, was given the job of solving the problem. Carlowitz made a number of proposals:

- Practicing "Holtzsparkünste" (the art of saving timber) by applying energy-saving stoves in housing and metallurgy and by improving the heat-isolation of buildings.
- Searching for 'Surrogata' (substitutes) for timber, such as peat.
- Cultivating new forests by "sowing and planting of wild trees".

In 1713 von Carlowitz published the book *Sylvicultura oeconomica*, the first comprehensive handbook of forestry. The 400 page book deals with the question, how to achieve "Conservation and cultivation of timber, a continuous, steady and sustained use". The concept of *Sustainability* (Nackhaltigkeit) appears for the first time in his book on forestry.

Also in mid Sweden forest was a critical resource. Wood was burned to heat the rock and crack the mountain to mine the iron ore; it was used to reduce iron from its oxides, and to melt it in the blacksmiths' ovens. Sweden was then the largest iron exporter in the world, feeding the wars in Europe. Here Count Carl Johan Cronstedt of the newly (1739) formed Swedish Academy of Sciences, was asked to tackle the problem. Cronstedt was architect and highly active in mining affairs. After experimentation Cronstedt together with General Fabian Wrede introduced in 1767 the "kakelugn" a channelized stove, which very efficiently took up and stored the heat. It made Swedish energy technology the best in Europe, and meant much to reduce wood use for heating. Swedish homes got a reputation for being warm and nice.

It is interesting to see that the ways to deal with the resource crisis were then the same as today. *Management skills* – as in the handbook on forestry – and *technological solutions* - such as the channelized stove and insulation of buildings - and *substitution* for example by the use of peat are all on today's agenda.

Today again forests are in focus in the Sustainability discussion. Half of the original forests of our planet are gone. In the climate negotiations deforestation in the world have been recognised as a main reason for climate gas emissions, accounting for up to 25% of global greenhouse gases, and in the discussion on a global treatment the out-phasing of the fossils fuels are accompanied by the so-called RED, REDD and REDD+ Programmes which address “reduced deforestation and forest degradation” in developing countries. Almost the entire deforestation dilemma refers to tropical forests on the southern hemisphere. The boreal forests in northern hemisphere, including northern Europe, may however significantly contribute to reducing the emission by serving as a sink of atmospheric carbon dioxide, and they are included in the REDD negotiations.

1.4 The first steps towards sustainable development

As mentioned during the forest crises in Europe in the early 18th century the concept of sustainable development was used for the first time. Under various names and in different contexts the concern that humankind was in imbalance with the planet it was living on was then repeatedly brought up the following years. These concerns became the origins of the request for sustainable development.

Efforts to preserve landscape, wild life and habitat was the first step. As society expanded and inhabited large areas which had so far been preserved as wild and natural a movement for *nature protection* was growing in many countries. In the 19th century, especially in the USA, strong powers acted for the preservation of some of the country’s natural treasures. The first national parks were established at Yellowstone (1872) and Yosemite (1890). The ancient forests outside the protected wilderness areas were however ruthlessly destroyed by logging. In Europe the very first large national park in was established in Sweden in the far north (of little economic interest), from the early 20th century. From there on a strong nature protection movement develop further in the 20th century.

The *population explosion* and concern for Earth’s carrying capacity, a second step, was discussed already in the 18 the century. The Englishman Thomas Malthus in “An Essay on the Principle of Population” from 1798 alarmed the world that food and other resources soon would not be enough for everyone. This was the beginning of a discussion which is still ongoing. The theme was developed and given a wider audience by the Russian geochemist Vernadsky in a series of lectures on the “biosphere”, which he delivered at the famous University Sorbonne in Paris, France, in the 1920s. His question was *is the carrying capacity of the planet enough?* The Swedish/American Geographer Georg Borgström in the 1950s in several books warned for overexploitation of resources, and another Swede Hans Palmstierna talked about plundering the Earth.

Most researchers today believe that enough food for all will be possible, even with a global population of 10 billion, but looking at what is in fact happening we see steeply increasing land prices in many parts of the world, especially in Africa, and there may be reasons to be less certain about that.

1.5 Sustainable development enters the political agenda

The modern development to fight the dilemma of the unbalanced human-nature relationship begins in the 1950s and1960s provoked by the increasing environmental damage caused by *unregulated use, release and pollution by synthetic chemicals*.

Rachel Carson's book *Silent Spring* was published in 1962. It became famous as the whistle blower for a new environmental movement. It was followed by a flood of reports. It focused on the situation in the USA and described in some detail how American Companies marketed and sold new chemicals for commercial reasons thereby sacrificing the environment, while authorities did nothing to control or prevent it. Silent spring referred to a situation when insects were killed by chemicals and thereby the birds who fed on them also died, and by that no bird song.

In Europe a similar chain of events unrolled. In the 1950s scientists discovered how seeds doped for next harvest with methyl-mercury to kill off rodents was eaten birds and caused massive death of birds. Also marine pollution was serious. Poly Chlorinated Biphenyls, PCBs, was a particular harmful chemical for the environment. In 1964 Danish chemist Sören Jensen identified PCBs in a dead white-tailed eagle – they feed almost entirely on fish - and thereby started the process that finally led to the prohibition of PCB. In the 1970s the seals in the Baltic Sea were threatened by extinction – the cause turned out to be PCB. In Japan phenyl-mercury played a similar role. As it was released from an industry close to the village of Minamata it caused widespread disease and even death to both animals and people in the so-called Minamata disease.

Widespread pollution was a main reason for Sweden to start the process to collect a world conference on the global environment. It took place in Stockholm in June 1972. Experts from around the world participated, scientists as well as politicians and grassroots activists. Environmental issues and the struggle against poverty in Third World countries were connected by terms like ‚eco-development' or ‚environmentally sound development'. However it was too early for the term sustainable development to be part of the political vocabulary, even if that is what they talked about.

1972 was also the year when the 'Club of Rome' published '*Limits to growth*'. The state of the world was studied using systems dynamics. The research be-

Figure 1.5. Rio 1992. A picture of the 1992 UNCED conference Credit:UN Photo/Michos Tzavaros

hind the study was carried out by a groups of young scientist led by by Dennis and Donella Meadows at the Massachusetts Institute of Technology (MIT) in the USA. It said „We are searching for a model output that represents a world system that is: 1. sustainable without sudden and uncontrollable collapse; and 2. capable of satisfying the basic material requirements of all of its people". We will discuss further Limits to Growth in chapter 4.

Finally in December 1972 USA carried out its Apollo 17 flight to the moon. Astronaut Harrison H. Schmitt, took a breath-taking *photograph of the 'blue planet'*. For the first time mankind could take a look at the whole earth, in all its elegance, beauty and fragility. This snapshot, was to become the most published photograph in media-history. It made people all over the world recognize that they were citizens of one earth.

The follow-up of these events finally resulted in the formation of the United Nations World Commission on Environment and Development, also called the "Brundtland Commission" after its chairperson the Norwegian Prime minister Gro Harlem Brundtland. Their report *Our Common Future* was published in 1987. Five years later the *United Nations Conference on Environment and Development (UNCED)* was convened at Rio de Janeiro, Brazil, on 3-14 June

1992, 20 years after the Stockholm conference. Then the concept of Sustainable Development was in focus and became an important part of the political agenda.

1.6 So what is then Sustainable Development?

The Brundtland Commission agreed finally what they meant by sustainable development:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This is by far the most widely recognized "definition" of sustainable development. It is easy to understand from the perspective that sustainability is about long term survival and welfare of the planet and its people. However it can also be understood as an ethical (moral) statement, as one of three equities required by sustainable development. They are

- Inter-generational equity, justice between us living now and those living in a future world
- Intra-generational equity, justice between us living now together on the planet
- Equity between us and the rest of the living world

As there are hundreds of "definitions" of sustainable development, not just the one cited above, it may be better to make it as simple as possible, as proposed by Alan AtKisson:

- Sustainability is a state which can continue in the very long term
- Sustainable development is a development which takes us closer to sustainability.

We may also ask under which conditions it is possible to approach sustainable development. Here the proper use and management of resources again are in focus.

The four *physical conditions* for sustainable development proposed by John Holmberg, have been used in practiced by the Natural Step Foundation. They refer to the proper use of resources and non-accumulation of pollutants. They will be discussed in some detail in Chapter 10.

The four *biological conditions* reminds us about that

1) Ecosystems dispose of wastes and replenish nutrients by recycling all elements. This rule is today violated by the linear flows of resources we see today;
2) Ecosystems use sunlight as their source of energy. Today, human society uses a large amount of fossil fuel for energy, which leads to massive environmental impact;
3) The size of consumer populations are maintained so that over-use does not occur. Today, the size of the human population is increasing rapidly and over-exploitation of natural resources occurs;
4) Biodiversity need to be maintained. Today, biodiversity loss is very rapid, and constitute a loss of future resources.

In practice each person tends to have his/her own understanding of what sustainable development is. It seems to be quite personal, and has to do with what is important and valuable for that person. Still there are basic conditions which need to be fulfilled to be able to safeguard a good or at least acceptable life for future generations on planet Earth, regardless of personal preferences and ambitions. This is what this course intends to outline and describe.

Chapter 1 sources:

Introduction

Lars Rydén The Sustainable development course of the Baltic University Programme http://www.balticuniv.uu.se/index.php/introduction

The Great Acceleration:

Will Steffen, Paul J. Crutzen and John R. McNeill, Ambio Vol. 36, No. 8, December 2007. The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?

The resource crisis:

Lars Rydén The Sustainable development course of the Baltic University Programme http://www.balticuniv.uu.se/index.php/introduction

Chapter 2
The planet and its natural resources

2.1 Earth

We live on a planet uniquely endowed with a rich and beautiful mosaic of life forms, and we also have the unique responsibility of protecting and taking care of this mosaic. We are not separate from the environment, but part of it. This chapter describes the Earth from the perspective of its physical systems, material flows and natural resources. These systems and flows form the basis of the life support systems that made, and continue to make, life possible on the planet.

The planet itself has a sophisticated structure from which we have direct experience of only a minor part. The inner part is molten while the outer core is semisolid. The core is identifiable since it generates the Earth's magnetic field. The heat in the inner part of the planet comes mostly from radioactive decay. The heat from the Earth is used in many forms of technical heating systems, and provides a sustainable source of energy.

Around the inner core is the *mantle*. It floats on top of, or outside, the core since it consists of light elements such as silica, oxygen, magnesium, aluminium, sodium and potassium, forming a more or less molten, pliable rock. The mantle reaches down to a depth of about 2,900 km. During eruptions of volcanoes it appears on the surface as a floating molten rock material, called magma. Outermost, on top of the magma, is the *crust* of the planet. This is the solid rock with which we are familiar. It is in this perspective quite thin. Under the oceans it reaches about 10 km in depth and on the continents up to 40 km in depth, which is from 0.2 to 0.7% of the distance to the centre.

The most common type of rock on Earth formed from solidified magma and is called *igneous rock*. Included in this category are the fine-grained rocks from magma that cooled quickly after a volcanic eruption, such as basalt; and coarse-grained rock from slowly cooling magma, such as granite and gabbro.

Rock that has been modified by heat, pressure and chemical reactions, as exerted, for example, by tectonic movements or the weight of sediments, is called *metamorphic rock*. Common metamorphic rocks include marble, formed from limestone; and quartzite, formed from sandstone.

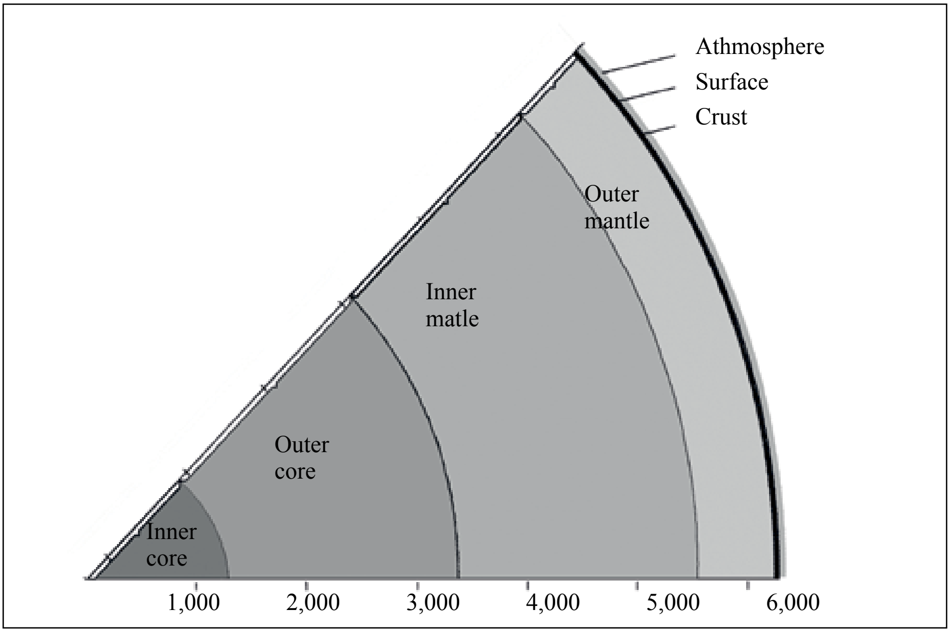

Figure 2.1. Structure of the Earth. The four major components of the planet are the inner and outer core and the inner and outer mantle, together constituting some 99.5% of the radius. On top of these is the outermost layer, the crust. It spans from 10 km in depth (under the oceans) to 40 km in depth (under the continents). The layer of soil on the surface of the crust on which life depends is, in this perspective, a minute and vulnerable outer skin. (Source: Environmental Science, Baltic University press, 2003).

Most rocks are very durable but exposure to air, water, and temperature variations eventually cause them to finally break up in the process of *weathering*. Examples of mechanical weathering are when water between fragments freezes, expands and causes a physical break; or simply when pieces are rubbed against each other during movements, e.g. by inland ice during glaciation. Chemical weathering occurs when a chemical reaction such as oxidation, or acidification caused by carbon dioxide, dissolves a component of the rock.

The particles created by weathering constitute *the soil*, and are transported by wind and water in the process of *erosion*. Finally, the particles are deposited in low parts of the landscape in the process of sedimentation, which creates valley bottoms and plains. Common soil types include till (rock-debris deposited by retreating continental ice), loess (very fine particles transported by wind), the coarse sand and gravel transported by water in rivers and brooks, and finally the sand, silt and very fine particles of clay that are deposited as sediment from the water column in lakes and oceans and thus make up ocean and lake bottoms.

Soil is found in valleys and plains, but also in other places where particles are kept from being carried away in the process of erosion. The sediments, e.g. in ocean bottoms, solidify due to the high pressure created by the continuous addition of new sediments. This rock forming process forms *sedimentary rock*. Examples of sedimentary rock are shale, sandstone, and conglomerates (aggregates of sand and gravel).

The creation of soil suitable for plants to grow in is thus based on very slow geological processes. Compared to the size of the planet, the layer of arable soil is small and sensitive. It is often not more than a few metres deep, and sometimes only a few centimetres deep, but it plays an important role in the geological formation of the surface of the Earth. Humankind needs to consider how to keep the soil layer in a state where it can continue to support life processes.

2.2 Rock and soil as resources

The Earth's crust, *also called the lithosphere*, contains minerals, metals, and other materials that are essential to human society. In fact, civilisations have been named after metals extracted from it. Stone, bronze (made up from copper and tin), and iron have been used to name periods of human history.

In modern times (after 2000), hundreds of different materials are extracted from the Earth's crust. The amounts of *metals* most extracted are 2800 mega tonnes iron, 47 mega tonnes aluminium, 22 mega tonnes manganese, 18 mega tonnes copper, and 14 mega tonnes chromium yearly.

However, the largest amounts are extracted of *sand and gravel*, used for example in brick, concrete and other forms of building material. As well, large amounts of limestone are used to produce concrete. In addition, considerable amounts of other materials are moved in connection with mining.

The landscape on the planet – the valleys and mountains, water and land, and rock outcrops and soil – is the result of recent processes in terms of geological time, and occurred in the Quaternary period (the last 1.6 million years). Man has made major changes to the landscape, especially during the last few generations. Examples are deforestation, drainage operations, and construction of infrastructure such as large dams for hydropower. The amount of material involved is large. It has been estimated that by building excavations, road building, and mining operations man moves about 35 giga tonnes of material per year world-wide. Sediments in rivers hold another 10 giga tonnes of material added by man per year. Other than plate tectonics, these man-made operations are the largest geological processes on Earth.

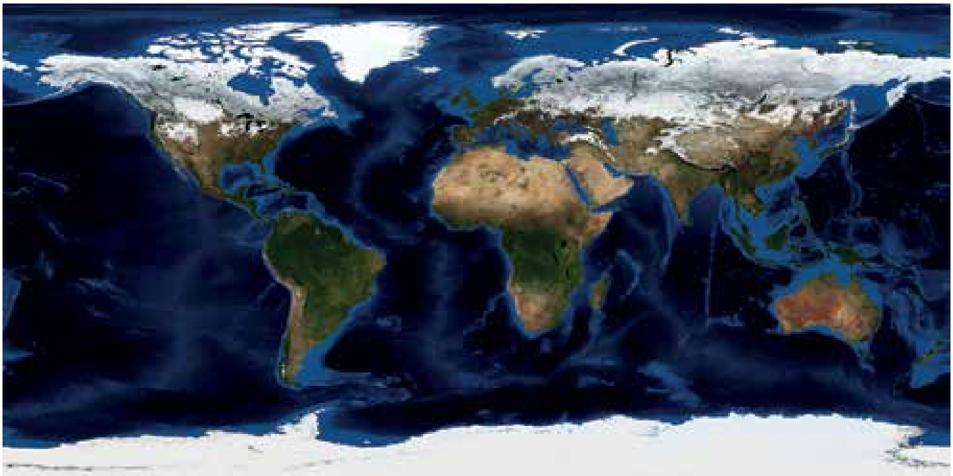

Figure 2.2 Blue Marble Earth. The Blue marble images are the most detailed true-colour images of the entire Earth to date. Using a collection of satellite-based MODIS observations, scientists and visualizers stitched together months of observations of the land surface, oceans, sea ice, and clouds into a seamless, true-colour mosaic of every square kilometre of our planet. Source: NASA Goddard Space Flight Centre. Credit: Reto Stöckli, NASA Earth Observatory. (http://visibleearth.nasa.gov/view.php?id=73580)

Soil is a key resource as it supports all organic life. In a typical soil profile, organic carbon concentrations are decreasing exponentially with depth. About the same amount of carbon is usually found in the upper 25 cm as in the subsoil between 25 and 100 cm depth. This can be visually observed when digging a soil pit where the darker upper horizon indicate a high carbon content compared to deeper horizons which are more greyish or reddish due to less amounts of minerals and oxides with organic material. Soil organic carbon content is a key-indicator for soil fertility since it affects soil structure and is positively correlated with aggregate stability, water infiltration, water holding capacity, nutrient delivery, nutrient use efficiency and soil erosion control. Therefore, keeping reasonable high levels of soil organic carbon is essential to sustainability.

But in contrast soil is lost at an accelerated rate. Society induced tremendous changes in the land surface area of the planet has deceased soil. Especially society has increased the speed of *erosion*. Biological processes slow down erosion, especially since plants bind soil in areas where it would otherwise be lost. However, if plants are removed by human intervention, erosion is speeded up. Erosion occurs whenever land is made barren of plants. The amount of soil moved by erosion from agricultural land is massive. Farmland is extremely sensitive to erosion by rain and wind when left in fallow for long periods. This is a major threat towards the productivity of large areas. The soil ends up in rivers where it is transported to lakes and oceans, adding to sediments and magnifying natural processes.

In addition modern agricultural methods, especially ploughing, have dramatically increased the loss of soil. A main reason is that as organic material is exposed to air, it is oxidised by soil microorganisms. It results in the emissions of carbon dioxide from land and contribute to climate change and loss of valuable soil. The large plains in Europe and North America have in this way lost meters of soil since they were colonized, while fertile areas in Africa, as well as the Amazonas, have undergone the same process because of overgrazing and deforestation. The world's population increases while the amount of productive farmland began declining in the 1970s. The United Nations Framework Convention to combat desertification was set up exactly to find ways to slow and reverse these processes.

2.3 The atmosphere and the sun

As described above we live on top of an immense layer of solid material, measured from the centre of the Earth. But we also live at the bottom of an immense "ocean" of air, the *atmosphere that* reaches up about 1,600 km. It is composed of gaseous elements, many of which are essential to life on Earth. The present oxygen content of 20% was probably reached about 300 million years ago. Simple oxygen breathing, mono-cellular organisms have been present for more than a billion years. Large animals, which require a higher oxygen concentration, appeared on a geological scale rather abruptly some 670 million years ago. Human beings cannot function well with a much lower oxygen concentration than is currently present. This can easily be experienced during high altitude mountain climbing.

The atmosphere is structured in four rather distinct layers. Closest to the surface of the Earth is the *troposphere*. It reaches up at the most 18 km at the equator and 8 km at the poles. The troposphere contains most, about 75%, of the mass of the atmosphere, simply caused by gravitation. The troposphere is where the weather phenomena occur. It is therefore very thoroughly stirred and, thus, has a quite uniform composition of gases. The temperature decreases throughout the entire troposphere by about 1°C per 100 metres, and is about -60 °C at the top.

The sun shines on the planet with an intensity of about 1,330 Watts per square metre at the outer reaches of the atmosphere, and varies according to location and time of year. About 25% of incoming solar radiation is reflected by the clouds and the atmosphere and does not contribute to the heat balance of the planet. The atmosphere and clouds absorb another 25%. Only half of the solar radiation thus reaches the surface of the Earth, some being again reflected, or backscattered.

About 45% of incoming radiation is finally absorbed by the surface of the planet. This energy is used for e.g. evaporation of water. All of it is, however, in the end radiated back to maintain heat balance. However, since the outgoing radiation comes from the colder Earth it is very different from the incoming radiation. It is mostly low energy, longer infrared wavelength radiation (heat radiation). The atmosphere is much less transparent to outgoing heat radiation than it is to the incoming solar light. Thus, much of the energy is used to heat up the lower atmosphere and indirectly the surface of the Earth. This effect contributes to the heat balance of the planet with about 35 ^{o}C. Without this effect, the Earth would not harbour life as we know it. The heating through absorption of infrared back radiation is called the "greenhouse effect," comparing the atmosphere to the glass in a greenhouse that makes the inside warmer by absorbing outgoing radiation. The most important component in the Earth's atmosphere that absorbs the infrared light from the Earth is water vapour. However, any gas that absorbs infrared light contributes. Most important are carbon dioxide and methane. The concentrations of each of these gases are decisive for the heat balance of the planet. The present dramatic increase of carbon dioxide and other greenhouse gases is obviously influencing this balance and causes a shift towards a warmer climate, called the *enhanced greenhouse effect.*

The gases of the atmosphere are important resources for mankind and all life. Carbon dioxide is incorporated (assimilated) when by photosynthesis organic material is built up. In this way huge amounts of carbon are sequestered from the atmosphere. Oxygen are used in all kinds of combustion processes. In calculations of material turnover oxygen is included, either as air or as oxygen gas itself. It is, however, never limiting. Nitrogen gas is used to produce ammonia for all kind of chemical needs, in particular as fertiliser. As gaseous nitrogen is a very stable diatomic molecule large amounts of energy is required to reduce it to ammonia in the Haber Bosch process. It is a main use of fossil fuels and thus contribute to climate change.

The solar input is the base for all life and energy on our planet. The energy available for processes on the surface of the Earth, such as the hydrologic cycle, photosynthesis and heating of soil layers and vegetation, is called the net radiation. This is the net income of energy to the Earth's systems. Net radiation consists of the nets of long-wave and short-wave radiation. In the energy balance of the Earth's surface the net radiation is distributed between sensible heat flux (heating air and vegetation), latent heat (evapotranspiration) and ground heat flux (heating the ground).

Fossil fuels are stored “solar energy” as it consists of organic material formed millions of years ago. To use this is not sustainable but the direct use of solar energy in one or several of it forms is sustainable. It is the most essential of natural resources and is not limiting. Presently society uses only less than 0.1 per mille of the incoming solar radiation.

2.4 The water planet

The third crucial component of the planet is water, or the *hydrosphere*. Water is a very special substance. It is part of all living cells. On average, about 70% of a living organism is water. It is a perfect solvent for all kinds of ions, charged molecules and many of the chemicals that make up the fundament of living cells. Water constitutes a liquid in a temperature range that is perfect for life, and in fact is the only substance with such properties. When it solidifies to ice it becomes slightly lighter and thus floats on liquid water, a behaviour which is also quite

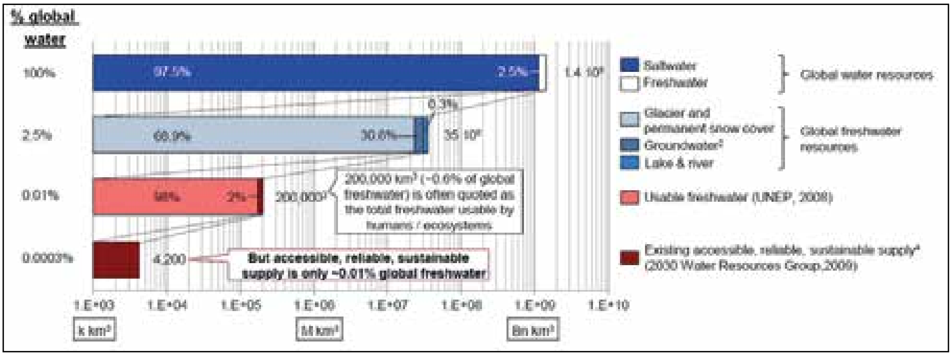

Figure 2.3 An Overview of the State of the World’s Fresh and Marine Waters. (Source: UNEP (2008); 2030 Water Resources Group (2009); “Charting our water future”; SBC Energy Institute analysis).

Notes:

1 The segments representing small percentages at the right – hand end of the first three bars have been enlarged for readability purposes;

2 Ground water includes shallow and deep ground water basins up to 2,000 meters, soil moisture, swamp water and permafrost;

3 Renewable internal fresh water resources (internal river flows and ground water from rainfall in a country), which amounted to 42,369 km^3 worldwide in 2011 (World Bank database), represent another theoretical upper limit for the water that can be withdrawn from natural systems but in practice accessible, reliable, sustainable supply is far lower (~4,200 km^3);

4 Existing supply that can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010; Net of environmental requirements, and excluding use of fossil (non-renewable) ground water reserves not sustainable in the long term.

unique. It takes a considerable amount of energy to vaporise water, and thus it stays liquid over an unusually wide temperature range.

There is about 1,403 million km^3 of water on the Earth. If this was evenly spread out over the planet, and if the surface was smooth, it would cover the whole Earth in a layer about 3 km deep. The surface is of course not smooth and about 70% of the surface of the planet is covered by water. Most water on Earth is not immediately useful to us. Ocean and saline water accounts for about 97.6% of all water on Earth. The rest, 33,400 km^3, is fresh water. Most of this is bound in ice and glaciers. Liquid fresh water makes up 4,400 km^3. It is distributed between about 4,000 km^3 of ground water and smaller amounts of surface water. Lakes, rivers and brooks, wetlands, etc., contain about 130 km^3 on the Earth as a whole, and the atmosphere holds about 13 km^3. Considerable amounts are contained in biota (65 km^3) and soil moisture (65 km^3).

Surface water is constantly re-circulated in what is called a natural *hydrological cycle*. Water evaporates from land, surface water and organisms. It enters the atmosphere and forms clouds as it condenses. It is transported by the winds and as it cools, especially at higher altitudes over mountains, it precipitates as rain and snow. Back on the ground it flows by gravity, coming back to the sea. The water flow described involves a considerable amount of energy. Mass (here water) present at higher altitudes contains *potential energy*, i.e., the flow down to lower levels represents an enormous amount of energy, which is used in e.g. hydropower plants.

Evaporation of water from land surfaces and transpiration from plants, called evapotranspiration, constitutes a considerable flow of water. In the reverse process, *condensation*, water vapour forms droplets of liquid water. Most often, condensation leads to cloud formation. When it occurs on ground or plant surfaces the water that appears is called dew. Some plants get all their water from dew. Precipitation occurs when water condensed in clouds forms large enough water droplets. Precipitation varies over the globe from several thousand millimetres per year down to almost zero. As a whole, the Aral Sea basin (1,76 M km^2) receives 65 km^3 of water per year. This corresponds to about 4 cm of water if spread out evenly over the entire region. This is the potential annual runoff from the region. Subtracting the annual evapotranspiration gives the actual yearly runoff. The *water balance* can thus be formulated as: runoff is equal to precipitation minus evapotranspiration. It is very low for the Aral Sea basin.

The hydrologic cycle includes the slow movement of ground and soil water. Here, movement is typically in the order of metres per year, as compared to metres per second for streams and metres per days for lakes. The storage of water

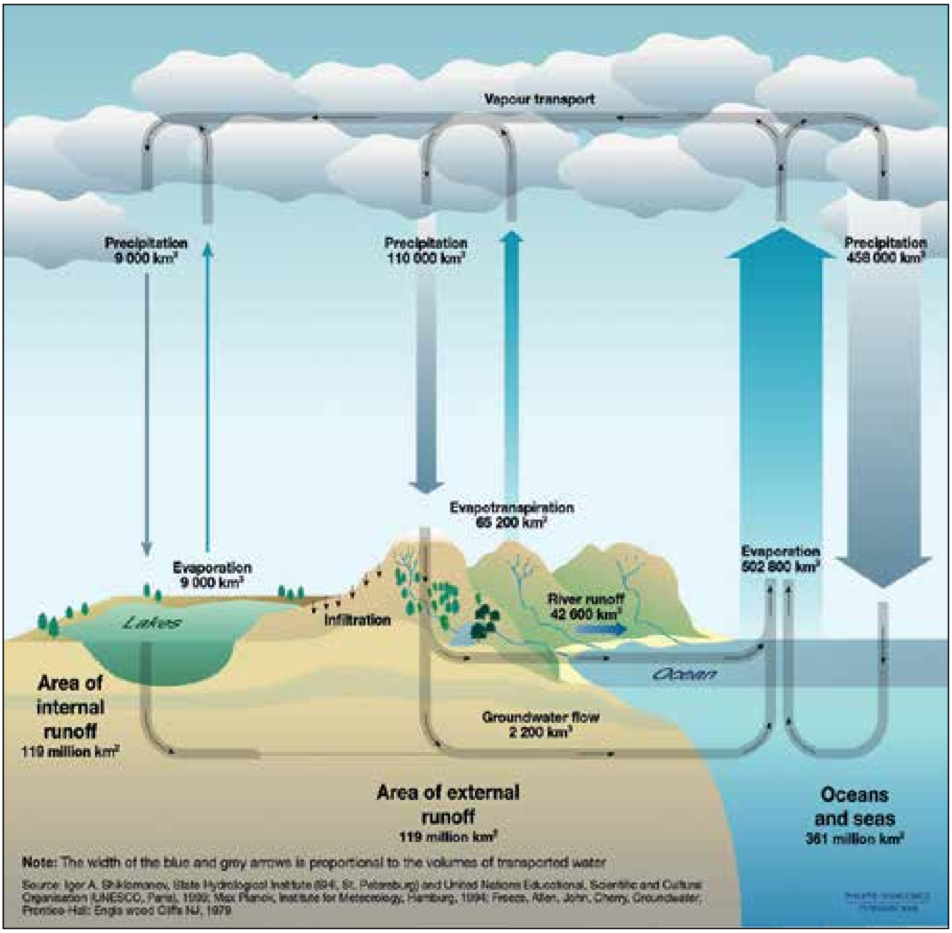

Figure 2.4. The water cycle consists of precipitation, vapour transport, evaporation, evapo-transpiration, infiltration, groundwater flow and runoff. Figure 1 explains the global water cycle, illustrating how nearly 577,000 km^3 of water circulates through the cycle each year. A table of estimated residence times shows the approximate times that water resources exist as biospheric water, atmospheric water and so on.

The world's surface water is affected by varying levels of precipitation, evaporation and runoff, in different regions. Figure 2 illustrates the different rates at which these processes affect the major regions of the world, and the resulting uneven distribution of freshwater. Water is transported in various forms within the hydrologic cycle. Shiklomanov in Gleick (1993) estimates that each year about 502,800 km^3 of water evaporates over the oceans and seas, 90% of which (458,000 km^3) returns directly to the oceans through precipitation, while the remainder (44,800 km^3) falls over land. With evapo-transpiration and evaporation totalling about 74,200 km^3, the total volume in the terrestrial hydrologic cycle is about 119,000 km^3. Around 35% of this, or 44,800 km^3, is returned to the oceans as run-off from rivers, groundwater and glaciers. A considerable portion of river flow and groundwater percolation never reaches the ocean, having evaporated in internal runoff areas or inland basins which lack outlets to the ocean. However, some groundwater that bypasses the river systems reaches the oceans. Annually the hydrologic cycle circulates nearly 577,000 km^3 of water (Gleick, 1993). http://www.unep.org/dewa/vitalwater/jpg/0102-water-cycle-EN.jpg in the ground and soil functions to even out water supply in nature. Even after prolonged draughts, some water is left in the soil and as ground water.

There are two implications of these aspects of water storage. First, seasonal water balances must include changes in the amount of water stored in the ground and soil. Second, polluted ground water moves slowly and may remain a problem even for future generations.

The water balance is connected to the heat balance by evapotranspiration. Net radiation is the driving force and sets the limit for evapotranspiration. In this way, the hydrological cycle is powered by precipitation which is the mass income, and net radiation is the power source.

The hydrological cycle thus constitutes a large solar powered pump that moves water and substances carried by water. Water evaporates in warmer areas, is transported by weather systems and precipitates in other colder areas. Many organic pollutants are in this way transported from southern areas to the north and even further north, to e.g. Greenland, which thus receives pollutants that did not originate locally.

2.5 Water as a resource

Water resources have probably influenced humans more than any other natural resource and are still one of the most important prerequisites for civilisation. Since human beings first settled, easy access to drinking water and water as a transport medium has been necessary to stable and lasting settlements. A quick glance at a map still shows a concentration of villages and cities to coastlines and rivers. In areas where freshwater is scarce the inhabitants spend a considerable amount of time every day collecting water, and development of such societies has been slow. In the developing countries, at least one fifth of the people living in cities and three quarters of the rural population lack access to reasonably safe supplies of water, while many of the industrialised countries are experiencing serious problems regarding water pollution, scarcity and wasteful use.

The availability of freshwater in terms of location and quantity is essential to all societies and consequently there are few natural resources of which our knowledge is more advanced. Despite this extensive knowledge, the exploitation of water resources is done on such scales, ranging from individual households to cities of several million inhabitants, that even more detailed knowledge, especially concerning interaction between the different users, is called for.

A further complication is the variability of water availability, not only spatially but also temporally. In many areas of the world freshwater is scarce, which creates a problem if the population demand is not in harmony with the available resources, even if these areas normally have spots of high water availability, e.g. oases. Availability is also an issue in areas where water is plentiful, but where the quality is low because of pollution, or where the demand is extremely high.

Around the world we see today surface water, water in rivers and lakes, to be overused. A most blatant case is the Amu Darya and Syr Darya drainage basin, where water has been extracted for irrigation to the extent that the Aral Sea is almost disappearing. Another case is the Colorado River, one of the largest river in North America, which for millions of years have been flowing from its sources high in the Rocky Mountains to channel water south nearly 2 500 km, over falls, through deserts and canyons, to the lush wetlands of a vast delta in Mexico and into the Gulf of California. Since the 1920s, Western states began dividing up the Colorado's water, building dams and diverting the flow hundreds of miles, to Los Angeles, San Diego, Phoenix and other fast-growing cities. The river now serves 30 million people in seven U.S. states and Mexico, with 70 percent or more of its water siphoned off to irrigate 3.5 million acres of cropland. Today we can see lines in the rock walls, distinct as bathtub rings, showing the water level some 4 meter lower, as it happens, since 2000.

Just as river waters have been over-used and polluted in many parts of the world, so too have groundwater aquifers. Groundwater tables are thus sinking all over the world, to the extent that many areas are already experience severe water

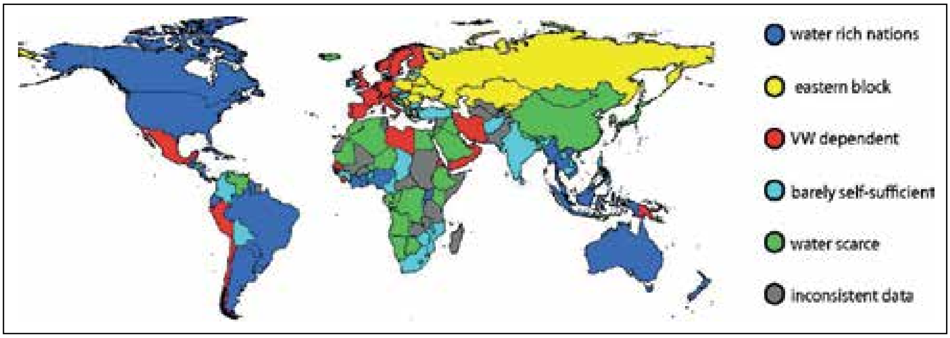

Figure 2.5. Worlds water resources. Map of the world's countries classified on the basis of their dependency on local (loc) and virtual (V) water resources, based on data for the 1996–2005 period. Countries are water rich when their mean population, X, is less than 0:8 Kloc (K_{loc} =average local carrying capacity); virtual water dependent if $K_V > X >$1:20 K_{loc} ; barely selfsufficient if $K_{loc} \approx X$ (i.e., 0:80 $K_{loc} < X <$1:20 K_{loc}); and water scarce if $X > K_V > K_{loc}$ (V= virtual water). Countries for which the data exhibit inconsistencies (i.e., $X > K_{loc} > K_V$) are shown in gray. A separate analysis has been carried out for the countries from the influence zone of the former Soviet Union (or the "Eastern Bloc") because in the past two decades their demographic dynamics have been affected by major political changes not related to freshwater resources. (Source: Samir Suweisa, Andrea Rinaldob, Amos Maritana, and Paolo D'Odoricod www.pnas.org/cgi/doi/10.1073/pnas.1222452110.)

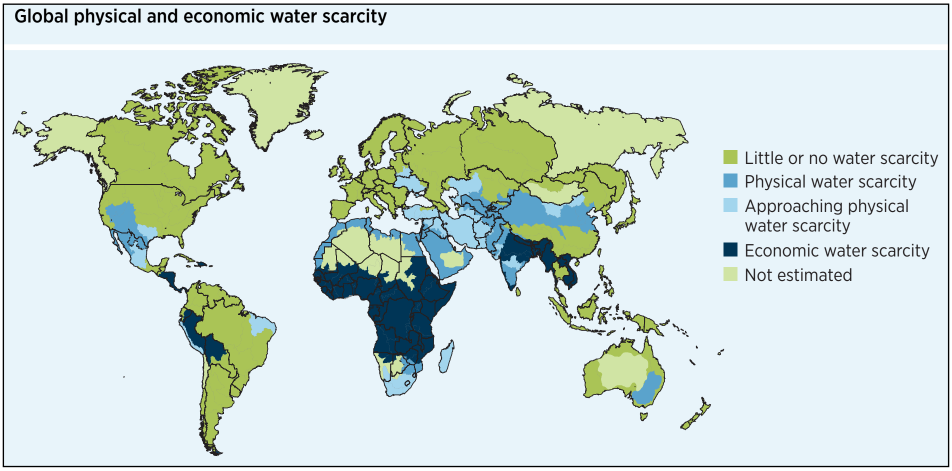

Figure 2.6 Water scarcity. (Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2, p. 11). © IWMI, used under licence.)

scarcity or are in risk of doing so. Climate change will likely increase the problems. Droughts will last longer. Higher overall air temperatures will mean more water lost to evaporation, and that water will be scarcer during the growing season,

Other regions - the Mediterranean, southern Africa, parts of South America and Asia - also face fresh-water shortages, even outright crises. In the Andes Mountains of South America, glaciers are melting so quickly that millions of people in Peru, Bolivia and Ecuador are expected to lose a major source of fresh water by 2020. In south-western Australia, which is in the midst of its worst drought in 750 years, fresh water is so scarce the city of Perth is building plants to remove the salt from seawater. More than one billion people around the world now live in water-stressed regions, according to the World Health Organization.

2.6 Use of carbon

Human activities have substantially altered both pools and flows in the natural carbon cycle. Combustion of fossil carbon and deforestation are the main causes for the 30 per cent increase in atmospheric CO_2 concentrations. A continued increase is expected to cause significant climatic changes. This will be further analysed in the following chapters. Here we will briefly highlight various features that need consideration when discussing the societal metabolism of a future sustainable society, in terms of utilisation of fossil carbon and biospheric carbon. For food and many materials, human society still completely depends on products of photo-synthesis and, until the middle of the 19th century, biomass also dominated global energy supply. Although fossil fuels have taken over as the dominant source of energy, biomass still accounts for more than 10 per cent of global primary energy supply and is widely used in developing countries.

Approximately 75 per cent of the global energy supply is based on fossil fuels, namely, coal, oil and natural gas. Combustion of both fossil and biomass carbon gives rise to CO_2 emissions but emissions from biomass burning are recaptured by plants if they are regrown. Thus, biomass has the potential to be a CO_2-neutral energy technology. At present, combustion of fossil fuels give rise to emissions of 6.0 Gton C/year and land-use changes, mainly deforestation of tropical rain forests, give rise to an additional 1-2 Gton C/year.

The use of fossil carbon is around ten times larger than the total use of all metals in society. It is also worth noting that fossil fuels contain vast quantities of heavy metals and other elements. Flows of elements associated with the extraction of fossil fuels are actually greater than the amounts that are mined for several elements, for example, aluminum (Al), vanadium (V), lithium (Li), gallium (Ga), beryllium (Be), mercury (Hg), silicon (Si), germanium (Ge), sulphur (S) and selenium (Se).

Fossil carbon is also used to produce plastics and other organic chemicals, for example, lubrication oils, solvents and printing inks. When eventually broken down these will also give rise to emissions of CO_2. In addition, some specific industrial processes give rise to net emissions of CO_2. Changing the production process may eliminate all greenhouse gases associated with a certain industrial operation. Although, there are some cases where the release of greenhouse gases is intrinsic to the product, making materials substitution is the only option for reduction of greenhouse gases. Cement production is one such example, where process-related emissions contribute 40 per cent of total emissions of lithospheric CO_2 to the atmosphere (in calcination CO_2 is driven off from the carbonates). This means that they are much lower than energy-related emissions but, in a future global industrialized society, these emissions alone may reach a rate which is high enough to cause atmospheric concentrations to continue to increase even if emissions from the energy sector are phased out.

Societal use of biomass and fossil fuels also leads to unintentional emissions of carbon in the form of methane. Emissions originate from leakage of natural gas, coal mining, biological processes in oxygen-poor environments such as rice paddies and digestion by ruminants. Global anthropogenic emissions are around 0.4 Gton/year, which is more than twice the natural rate of methane emissions.

2.7 The macronutrients and the environment

The macronutrients – nitrogen (N), sulphur (S), phosphorus (P), calcium (Ca), potassium (K), sodium (Na), magnesium (Mg)) – are elements needed in relatively large amounts in living organisms. The environmental status and availability of the macro-nutrients are very important for the composition, growth and vitality of ecosystems.

The conversion of macro-nutrients in nature is to a large extent connected with biological processes. These extensive processes heavily influence the state of the environment, for example, the acidity in soil, the chemical composition of surface waters and the radiative balance and chemistry of the atmosphere. In the evolution of the Earth, biological processes have been a major factor in the shaping of the cycles of the macronutrients, now determining the conditions for the biota in various ecosystems.

A major disturbance of the natural nitrogen flows comes from an intensification of the nitrogen cycle by increased fixation. Global fixation has increased by a factor of two or three. With the present excess fixation rate, the accumulated fixation over 50 to 100 years would correspond to the total amount of nitrogen stored in the living biomass. Nitrogen is fixed industrially in ammonia synthesis. Ammonia is a basic chemical in industry and nitrogen is contained in products such as nylon. However, the production of fertilizers for the agricultural sector produces the main demand for ammonia and is the major contributor to anthropogenic nitrogen fixation. To increase crop yields, biological nitrogen fixation is also enhanced by the choice of nitrogen-fixing plants (through symbiosis). Large amounts of nitrogen are stored in organogenic soils. Agricultural uses of these soils often rapidly activate and deplete this storage together with the organic material.

Fixed nitrogen is also emitted in combustion processes. This nitrogen has two sources. Some of it originates from the combustion air (thermal nitrogen and prompt nitrogen). Nitrogen is also present in the fuel (fuel nitrogen). The extraction of fixed nitrogen with fossil fuels amounts globally to approximately 60 Mtonnes per year, which is the same order of magnitude as from chemical fertilizers. However, only a fraction of the fuel nitrogen reaches outside the combustion process because of pyro-denitrification of the fuel nitrogen in the combustion process (or because of any added nitrogen emission counter–measures.) The net effect on the balance of fixed nitrogen in the ecosphere depends on the fuel source. For fossil fuels there is a net contribution, while burning of biomass normally gives a net loss. Most of the fixed nitrogen is emitted as various nitrogen oxides, in summary written as NO_x.

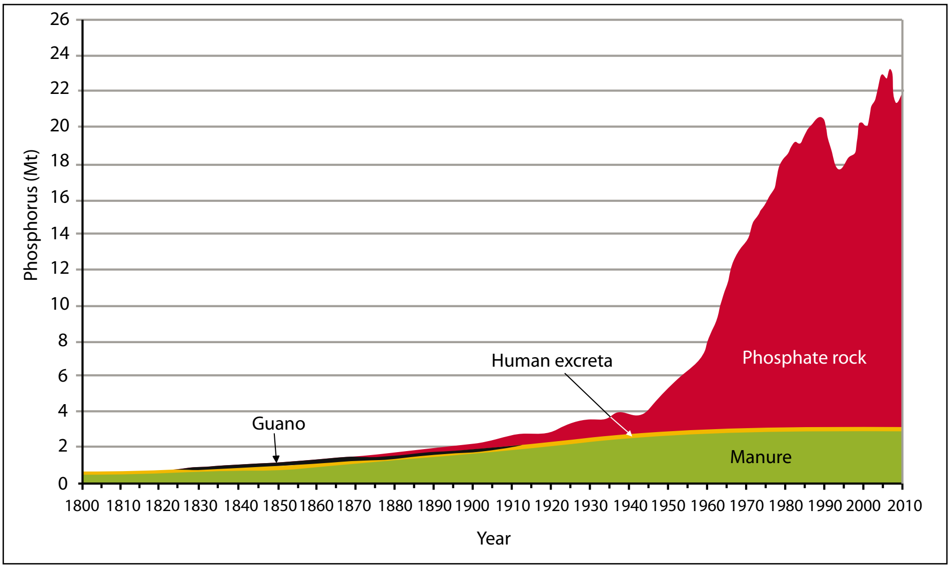

Figure 2.7 Global sources of phosphorus fertilizer. Since the mid-1940s, population growth accompanied by greater food demand and urbanization have led to a dramatic increase in the use of mined phosphate rock compared with other sources of phosphorus. (Source: Cordell et al. (2009) and Source: UNEP Year book 2011)

Fixed nitrogen leaves the ecosphere through decomposition of nitrogen compounds to N_2, mainly through biological denitrification of nitrate into N_2. By sedimentation, part of the nitrogen is also withdrawn from chemical activity in the biosphere.

Combustion of nitrogen-containing biological materials may also contribute to losses of fixed nitrogen from the ecosphere. The burning of biomass in the tropics has been estimated to yield a loss of 5-52 Mtonnes organic N, which can correspond to a substantial fraction of the total biological nitrogen fixation in the area and may lead to a deficiency situation. Combustion of nitrogen-rich biomass, such as forestry residues, in boilers with low emissions of fixed nitrogen (partly or wholly due to regulations) resulting in a net pyrodenitrification has been suggested as a way of compensating for the nitrogen excess due to air deposition in industrialized countries.

Sulphur in a reduced form can easily be oxidized and give rise to acidification. The main human-induced problems associated with the sulphur cycle are thus connected to emission to the atmosphere or exposition at the Earth's surface of not fully oxidized sulphur. Sulphur is extracted from the lithosphere in different ways:

- with minerals rich in sulphur, such as native sulphur or pyrite, that are extracted for their sulphur content;
- as sulphur impurities in fossil fuels;
- in metal-bearing sulphide minerals;
- as sulphates, mainly gypsum.

The first three forms contain sulphur in a reduced form, while in gypsum, a hydrated sulphate salt, the sulphur is already oxidized and neutralized. Most sulphur extraction takes place with the extraction of fossil fuels, especially coal. Half of the sulphur in fossil fuels is emitted to the atmosphere. Less than half is caught in ashes or in desulphurization plants or is recovered for industrial use.

The mining of sulphidic metal ores gives rise to sulphur in mine tailings and dumps and brings sulphur into metallurgical processes. On a world-wide scale the mean recovery factor of sulphur in global copper production is around 70 per cent.

The world-wide industrial use of sulphur is around 60 Mtonnes/year, that is, less than one-third of what is extracted from the lithosphere; see Figure 6.2. More than half of the sulphur is extracted from the by-flows associated with fossil fuels use and metals production. The major proportion is used for production of sulphuric acid which has a very diverse use in industry, although around 58 per cent goes into the extraction of phosphorus, another macronutrient used mainly in the production of fertilizers. For each kilogram of phosphorus, about two kilograms of sulphur are needed.

Anthropogenic emissions, mainly from the industrialized countries, make up three-quarters of total emissions. The transfer from the lithosphere is largely caused by the anthropogenic contribution, which is concentrated in the mid-latitude northern hemisphere. Society has increased the transfer from the lithosphere to the atmosphere by about a factor of 10.

Phosphorus is extracted from the lithosphere, mainly in the form of various apatites (principally calcium phosphates). The main societal use of phosphorus, about 90 per cent, is as fertilizer in agriculture. Approximately 22 Mt (megatons = millions of tons) of phosphate rock were used in agriculture in 2011. Extraction has increased dramatically with the enhanced use of fertilizers (4.8 per cent/year since 1900). Phosphorus is also used as an additive in food and fodder. The second largest use is as a component in washing detergents. The use of phosphorus thus occurs to a very large extent within the food sector. In its other uses, most of the phosphorus is discharged in waste water. It is a main cause of large scale eutrophication of coastal waters.

Base cations are extracted from deposits of sediment and evaporites in the lithosphere. They are used as fertilizers and pH-regulators in agriculture, as base chemicals in industry and in the manufacture of cement, which has led to their accumulation within infrastructure and buildings.

Base cations are brought with the extracted fossil fuels. Burning fossil fuels gives alkaline bottom and fly ashes. Earlier the fly ash partly compensated for the acidic components in the exhaust gases. But the fly ash is easily caught in filters and was one of the first emissions to be decreased, thus increasing the acidification potential of the untreated parts of the emissions.

Besides the increased input in the macronutrient cycles, *there is an increased leakage and redistribution of the nutrients available in the ecosphere*. The substitution of highly manipulated cultural ecosystems for natural ecosystems in agriculture, and also to some extent in forestry, and intensive animal husbandry have led to large increases in the leakage of nutrients, especially nitrogen, to air and water and further to various ecosystems. Their leakage varies with the specific system and the applied practice, but is larger than in the natural system they have replaced. While natural systems have been forced during evolution to develop and rely on fairly closed nutrients cycles, agricultural ecosystems are driven towards other goals and also have the possibility of being compensated for their losses of nutrients. For nitrogen, the major leakages are ammonia to air from stables and manure and nitrate to water from agricultural soils. Ammonia (NH_3) emitted to air is the source of approximately half of the atmospheric deposition of nitrogen compounds in Europe.

Within societal systems for growing, handling and using organic materials, there are large redistributions of nutrients bound to organic materials taking place at various levels and scales. In agriculture, specialization leads to fodder redistribution and concentration of nutrients in animalrich farms and regions. In soils with no recycling of harvested products, nutrient deficiency will quickly develop if there is no external supply. Trade in food and fodder takes place on a global scale, depending on, for example, soil abundance and conditions for growing different crops and economic circumstances.

2.8 Metals in nature and society

Today, approximately 30 metallic elements are made commonly available in society through mining and processing of their ores. Many metallic elements are used in their pure forms, however, because of their unique properties. Chemical mixtures (alloys) of two or more metals, or metals and non-metals, often have superior properties of corrosion resistance, durability or strength.

Iron totally dominates societal use of metals; compared to other materials flows in society, the flows of metals, except for iron, are relatively small. But metals are technically and economically very important to industrialized society and this is reflected in their relatively high prices. Many other metals are closely linked to the use of iron as *ferro-alloy metals*. Partly because of their relatively low weight, society uses an increasing amount of the abundant light metals, especially aluminium, but also titanium and magnesium. Society still also uses a lot of the traditional *non-ferrous metals* or *base metals*, for example, copper, lead, zinc, tin and mercury.

The *precious metals* of antiquity, gold and silver, were called noble metals. Today the so-called platinum group elements are also called precious or noble metals because they too exhibit non-reactive properties.

Finally, there is a group of metals, the *special metals* that do not fit into the categories mentioned above. These metals have unusual properties that make them important in industry. Tantalum, for example, is widely used in electronics because of its special properties.

Many metals are scarce but valuable and are therefore extracted from ore of a low grade. Despite the relatively low volume of extracted useful metals, *some metals contribute extensively to the ecological rucksack, that is, mining waste.* Iron, because of the large volume used in society, and copper, because of its low-grade ores, give rise to huge amounts of discarded useless materials in mining and concentrating operations and also in subsequent metallurgical processes.

The extraction of five grams of gold (about the amount in a wedding ring) needs the excavation of around one cubic meter of lithospheric materials. The rucksacks consist mainly of large dumps and translocations of materials at the mine and may give rise to mainly local effects. They are therefore probably of minor importance from the perspective of sustainable development. If mining is done in agricultural areas, it can imply serious problems for these areas. Leakage of metals from mines and overburden can also imply long-term effects on the local environment.

Emissions of metals to the environment can occur all along the chain from the cradle to the grave. Emissions from the production system have historically increased with increased production during industrialization. Fortunately, the environmental restrictions introduced in later years have drastically reduced these point emissions to water and air from the production system. Instead, today, major emissions of metals to the environment in modern industrial systems tend to emanate from the consumption phase of the goods and not from their production.

There is a huge range in consumption losses between various types of use of metals. We have uses of metals that are intrinsically dissipative in their character. In chemical uses especially, metals are spread intentionally either already as products or in their uses as in, for example, paints and biocides. However, there are also intentional losses involved in metal uses, such as the lead used in ammunition. Losses from wear and tear or corrosion of products also vary considerably. For example, use of copper that give rise to emissions include, copper used outdoors and exposed to weathering as in roofing and facing materials, copper exposed to liquid flows as in tap-water systems and heat exchangers and copper in braking pads. The dissipation of the metals are concentrated to the places where the metals are used, that is mainly in towns and villages and where our industry and infrastructure are located. Locally the emissions to soil and water can be very high. However, for metals, the major system losses tend to emanate, not from direct emission to the ecosphere, but from *lack of recycling*. System losses mean metals in the technosphere that are taken out of use but are then are not recycled such as flows to deposits through waste-handling or materials simply left behind when no longer in service. The copper flow illustrates this. Large flows of copper recovered by the waste-handling system are not recycled, but are ultimately deposited in land-fills. A lot of copper in cables laid down in the ground, for example, is not recovered when the cables are taken out of service.

When recovered metal is of suitable quality, today's production technology often makes it possible to keep a very closed metal system, which can be exemplified by the lead system. This is also underscored by the fact that secondary production of metals often has much less specific loss than the corresponding primary production.

Potentially extractable metal ore deposits are suffering from various degrees of scarcity. Extraction is coupled to extensive manipulation and the intensive and often dissipative use of metals has led to severe contamination of the environment and threats to human health. Certain metals that are scarce in nature are not scarce in society. The relatively large use of many of the scarce heavy metals compared to natural turnover has an important implication: societal use of these metals has a large potential for producing substantially increased concen-trations of them in the ecosphere. Limited assimilative capacity in natural systems sets restrictions on the uncontrolled emissions of these metals. Contamination by heavy metals has also been a serious environmental problem so far during industrialization. The light metals are in a better position in that their societal use is small compared to natural turnover.

Metals can be separated in two main groups, abundant and scarce, on the basis of their abundance in the Earth's crust. The *abundant* metals are those that individually make up at least or almost 0.1 per cent by weight of the Earth's crust. There are very few such metals: iron and the light metals aluminium, magnesium and titanium and then, at almost 0.1 per cent, manganese. All other metals occur in much lower concentrations, near to 0.01 per cent and less, and are categorized as geochemically scarce metals.

The abundant metals are available in increasing amounts in lower grade down to the common rock, from which they can be mined directly. It is argued therefore, that society will never experience a sudden scarcity of these.

All metals are mined from ores rich in specific separate minerals containing metals. The ores are ground and the metal-bearing minerals are separated and concentrated before metallurgical treatment in which the metals are extracted from the minerals. In the Earth's crust, however, the scarce metals are very seldom concentrated in separate minerals, but most often are found, in small concentrations, stochastically distributed as substitutes for other elements in the minerals of ordinary rock. It is not possible to grind these minerals to separate specific atoms or molecules. Instead the metallurgical process has to treat all of the ordinary rock, which make the metal practically unavailable. This has been called the 'mineralogical barrier'. It has been estimated that not more than one in 104 to 105 of the total amount of each metal is located in a separate mineral. This can give a rough estimate of the ultimately recoverable amounts.

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Chapter 3
System properties of resource flows

3.1 A systems perspective on resource flows

Resource flows make up a large system. The core elements of this system are energy and materials. Another part of the system is Nature/Environment with its components and another again is society with its economy, technologies and social needs and uses. To be able to analyse and discuss resource flows we need to be aware of at least the most essential elements of this large system and how they are connected. We also need to be acquainted with the most basic systems terms used in such an analysis.

A flow is *linear* when is does not return to its origin. In sustainability science linear flows are flows which goes from a resource to a waste. The resource is extracted from a source, used and wasted.

A flow is *circular* when the material is returned to be used again, it does not end its life as waste.

A *source* is where the resource is found, often in higher concentration than on other places. This is particularly clear when it comes to minerals, which are mined at sources where one finds them in higher concentrations. A source may hold a large amount of a particular resources, such as a metal or a fuel, e.g. oil. It is then called a *deposit* or a *stock*.

A *sink* is a place where a resource flow ends such that the material is stored for a long time. For example a forest which fix carbon, from the atmospheric carbon dioxide, as part of its photosynthesis acts as a sink for carbon.

*Stock and flows diagram*s often depict how the stock is either, *increasing* because of ingoing flow or *decreasing* because of outgoing flow, or both. For example a growing forest from which timber is extracted has both and ingoing and an outgoing flow of carbon. The ingoing flow is the photosynthesis which is increasing the amount of material in the forest and the outgoing flow is the harvesting of timber, which is taken out of the forest.

Resources can be either renewable or non-renewable. A *renewable resource* is constantly filled up. If it is harvested at a rate which is comparable to the rate in which it is replenished it is shown in a stock and flow diagram as fairly constant.

Its use is then sustainable. A renewable resource, such as the fish stock in a lake, can also be harvested faster than it is able to reproduce. Then it will be emptied, and its use is not sustainable. A non-renewable resource is not filled up at all, or is filled up in a time frame, which is much slower than the rate at which it is used up. Thus fossil carbon is a *non-renewable resource* because it is formed in a time scale many million times slower than it is used.

There are resources which are *intermediate* in this respect. For example peat is formed in a timescale of a few thousands years. If it is harvested and used at a rate which is equivalent to its rate of formation, its use is still sustainable. However most authorities consider peat as fossil, meaning non-renewable. In a similar way iron, which if course is not renewed since it is a metal, is sometimes considered a renewable resource just because it is so plentiful; it will not be emptied by our society.

Feedbacks are important properties of systems. Feedbacks can influence a stock so it increases (positive feedback) or decreases (negative feedback). For example at present the Arctic Sea ice is decreasing. It leads to an increasing surface of water. The dark sea surface absorbs heat from the sun much more efficiently than the white ice, and thereby it heats up the water which in turn contribute to the melting of the ice, and the ice surface decreases even more. This is a positive feedback loop. Negative feedbacks normally contribute to regulation of the stock e.g. if a temperature regulation controls the flow of warm water in a heating system, and the higher temperature reduces the flow, it is a negative feedback.

When doing systems analysis one may do it in a very simple way, by only indicating the most important elements and how they are connected. One can draw so-called causal loop diagrams to trace the origin of an effect. An example is given below (Fig. 3.1).

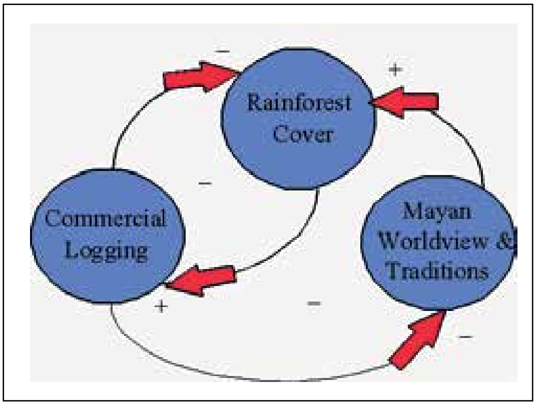

Figure 3.1 A causal loop diagram showing how the resource, the rainforest, is decreased by commercial logging. These two elements forms a negative feedback loop. The previous traditional logging, which was preserving and even increasing the forest, is influenced by commercial logging, which leads to the depletion of the resource. (Source: http://www1.american.edu/ted/ice/belize.htm)

3.2 Kinds of natural resources

There are different ways to group resources. A commonly used one distinguishes the following seven categories. 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. Macronutrients – especially 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, according to some analysis, 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, however, which are very abundant in the surface of the planet, will not be depleted by present levels of use, and are treated as renewables. 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.

Box 3.1 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.)

(Source: Box from Environmental management book 3, chapter 2)

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.

3.3 Resource availability

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.

Chapman and Roberts base their analysis of the seriousness of mineral extraction on data from Deffeyes. Figure 3.2 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.

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 distribu-

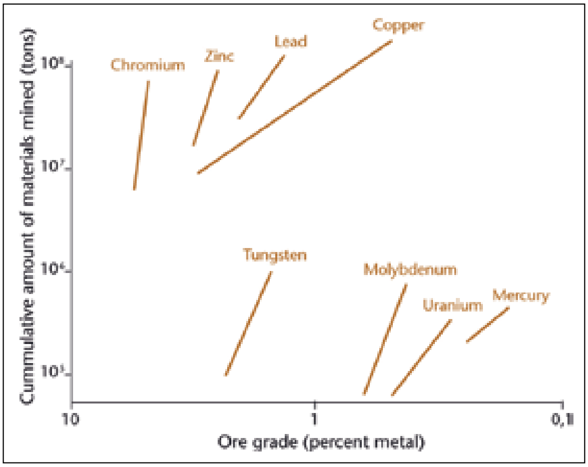

Figure 3.2 Slope of availability against grade for metals. If the slope is steep, much more resources are found as a lower grade ores are mined (Source: Chapman and Roberts, 1983).

tion 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. 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. Experience indicates that when an oil well has been 50 % emptied it has reach its peak, and its further extraction becomes slower and require larger efforts, both in terms in economic investments and energy required. The so-called EROI, Energy returned on energy invested, is decreasing, and the well becomes less profitable.

As conventional resources are getting more scarce oil from unconventional resources have become more important. Thus oil from deep sea wells, e.g. in the Gulf of Mexico on a depth of several thousand meters are now explored. Likewise oil is extracted from tar sand (oil sand) especially in Alberta, Canada, an activity which is quite polluting. Likewise the extraction of shale oil or gas by hydraulic fracking has increased dramatically the last few years; this is also environmentally costly and likewise more expensive that conventional oil and gas production. New techniques of (horizontal) drilling and pumping or also steam injection is needed.

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 the late Jurassic, some 150 million years ago. An-

Table 2.1 Fossil fuels sub categories (Source: 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

other 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 (Fig. 3.3) (Campbell, 1998). Most oil discoveries were made during the 1960s. From this and the present rate of extraction it is straightforward to predict the rate of depletion of conventional oil, which is now ongoing. However, the level of total oil production

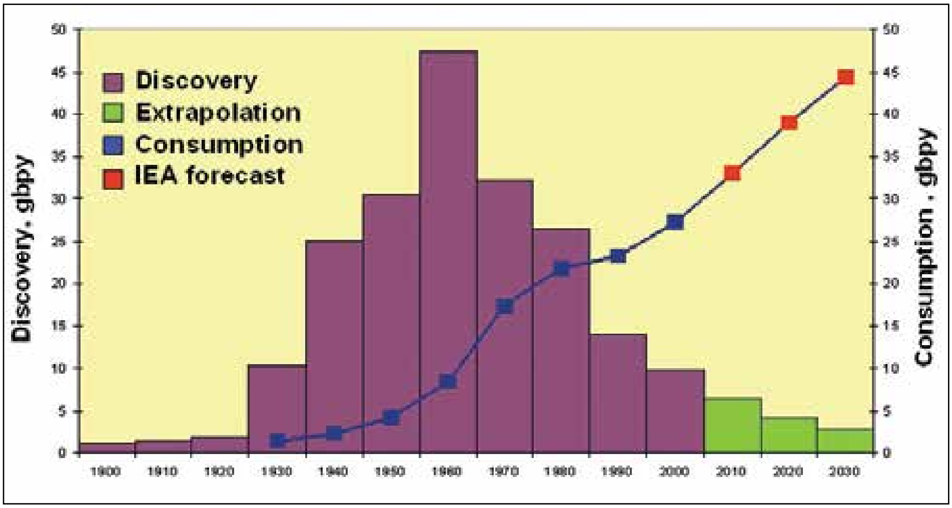

Figure 3.3 Rate of production vs the rate of discovery. Global oil discoveries peaked in the 1960s and are rapidly declining as oil becomes harder to find. Today there is a growing gap between new oil discoveries and production (gbpy = Gigabarrels per year). (Source: http://www.peakoil.net)

is since several years kept on a fairly constant level of 86 million barrels per day due to the increase of unconventional oil. Conventional oil production came to a peak in about 2007.

At present we see - against the predictions - a decrease in the price for oil and gas. Reasons seems to be that the alternatives are strongly developing, and that many investors are afraid that the climate change consequences for increased use of fossil carbon are so severe that a ban on the use, or at least a considerable taxation on the use of fossil carbon, is expected.

3.4 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.

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. 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.

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 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.

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 out-phasing 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.

3.5 The large size of the resource flows and its consequences

The resource flow on our planet is very large. 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. 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).

An estimate of the material flows on the planet as a whole (The Global Footprint Network, 2012) indicates that it is close to 50% 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 (McNeill, 2000). The carrying capacity of the planet was passed probably around 1980.

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.

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.

3.6 The carbon cycle

The carbon of the planet is found in the atmosphere as carbon dioxide, dissolved in ocean water, bound in biomass, and stored in the lithosphere as carbonate minerals. Although the atmosphere holds only 0.036% of CO_2 this substance is a key component in the physics of the planet since it interacts, as explained, with the heat balance. It is also essential to all living cells as it is used when new biomass is built up in carbon dioxide fixation.

The carbon cycle starts when carbon dioxide in the atmosphere is formed from carbonates in the lithosphere. Carbon has been added to the atmosphere, through volcanic activities, throughout the history of the planet. An important part of the carbon flow is the formation of calcium carbonate in the seas especially as shells in marine organisms. As these die and their shells sink to the bottom, carbonate is transferred from the atmosphere to the sediments which finally

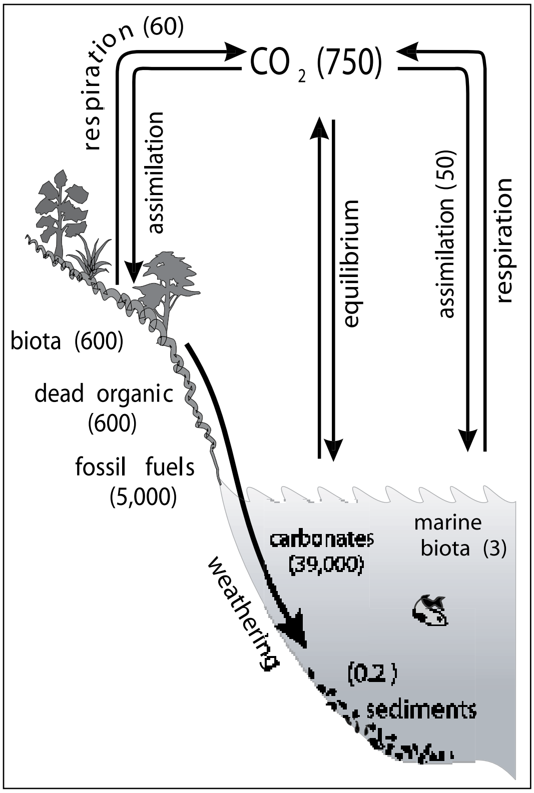

Figure 3.4. The natural carbon cycle. Carbon is available in the ecosphere as carbon dioxide in the atmosphere or dissolved in sea water as carbonates. A large amount is also present in organic form in living organisms or in dead organic matter in the soil and the sea. A rapid turnover between these two pools occurs through photosynthesis and respiration. The inorganic and organic pools correspond to around 400 and 20 years of photosynthesis, respectively. The carbon in fossil fuels, if used, is enough to significantly change the carbon concentrations in the atmosphere. The numbers denote for flows gigatonnes per year globally and for storages gigatonnes. (Source: Environmental Science, BUP, http://www.balticuniv.uu.se/environmentalscience)

become limestone rock, and thus return to the lithosphere. This slow, but in the history of the planet, major part of the carbon cycle, is estimated to have taken care of some 60 entire atmospheres of carbon dioxide, and that each carbon atom has made about 30 such round trips.

The absorption of carbon dioxide in ocean water is slow however, and in addition, limited by the slow mixing of the upper layer with the rest of the water in the oceans. An immediate component is the fixation of carbon dioxide to organic substances by living organisms during photosynthesis. As the biosphere builds up to considerable amounts of biomass, this constitutes a major carbon sink, not the least in the forests of the planet, but also organic material in soil.

Carbon dioxide fixation removes carbon from the atmosphere and respiration returns it back. In respiration organic molecules are oxidised with oxygen to provide energy to living cells. The by-products are water and carbon dioxide.

All kinds of combustion and decay processes add to this flow. Today, the comparatively immense utilisation of fossil fuels seriously disturbs the balance between

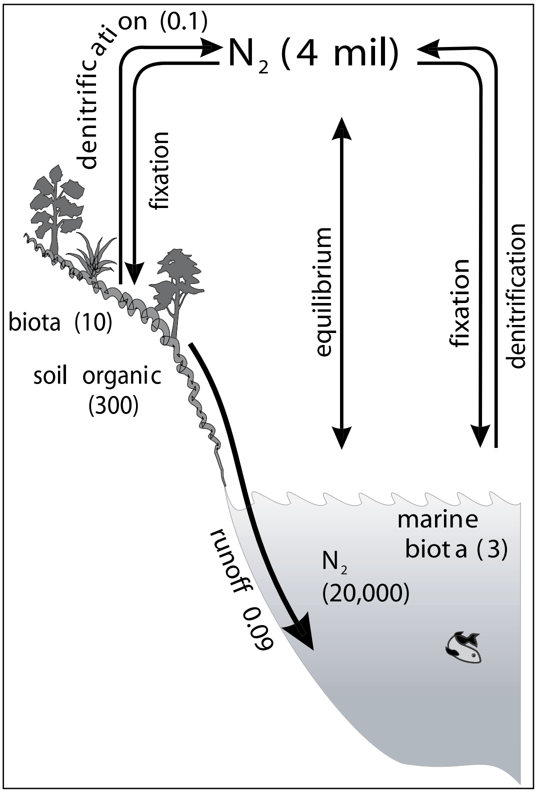

Figure 3.5. The natural nitrogen cycle. The Earth's crust contains relatively small amounts of nitrogen; most of the nitrogen in the ecosphere exists as the inert N2 gas residing in the atmosphere, and only about 1% is dissolved in the oceans. From an environmental point of view, the interesting part of nitrogen is not this inert pool, but the chemically and biologically active part, the so-called "fixed nitrogen" in the ecosphere. Nitrogen is fixed and brought into the biogeochemical cycles mainly by certain specific nitrogen-fixing microorganisms. A small amount of fixed nitrogen also comes from lightning, as atmospheric nitrogen is oxidized, as well as from volcanoes. The numbers denote for flows gigatonnes per year globally and for storages gigatonnes. (Source: Environmental Science, BUP, http://www.balticuniv.uu.se/environmentalscience/ch2/chapter2_g.htm)

natural processes. Modern combustion practices cause the concentration of carbon dioxide to increase. This increase is the key factor behind the enhanced greenhouse effect. The people of the Earth now consume 6 gigatonnes carbon/year, a mass that exceeds the mass of all the metals used by mankind during the period of time by a factor of ten! In addition, the handling of many fossil fuels involves flows of other matter than pure carbon, particularly sulphur (see below), which adds to the turnover of matter and many profound environmental stresses.

3.7 The nitrogen cycle

Nitrogen is found in the atmosphere at a concentration of 78%. It is present as a very stable diatomic nitrogen gas. This is natural in the oxidising atmosphere present today. However, it should be pointed out that when the atmosphere once was reductive, nitrogen was present as ammonium. All life forms were, already from the outset, dependent on nitrogen, which is a component in such fundamental bio-molecules as proteins and nucleic acids. Ammonium can be used directly while molecular nitrogen cannot, but some life forms, special bacteria, have developed mechanisms to convert nitrogen to ammonium by reduction. These nitrogen fixing bacteria play a key role in maintaining life on Earth and manage the biological flow of nitrogen from the atmosphere pool back to life forms.

The flow of nitrogen is rather complex when seen in all its detail. The nitrogen fixing bacteria produce ammonium, which is easily oxidised to nitrite and nitrate. This is taken up from soil by plants. Certain plants, such as clover and alder trees, harbour their own "private" N_2-fixing bacterial strains. As plants are broken down to detritus, the soil content of nitrogen compounds increases. Animals receive their nitrogen through food, especially animal food, and excrete this as urine, or for certain groups such as birds in other forms. This nitrogen may again be used by plants.

Finally, a series of bacteria uses nitrogen compounds as a source of energy and extracts this as they return the nitrogen to nitrogen gas. These denitrifying bacteria, present e.g. in many aquatic environments, work in oxygen depleted conditions.

In general, nitrogen is a limiting nutrient for plants. Since ancient times, "fossil" nitrogen, e.g. deep layers of bird droppings, have been used to provide agriculture with extra nitrogen as fertilisers. In the early part of the 20th century, an artificial method for reducing atmospheric nitrogen, the Haber-Bosch process, was developed. By using this process, modern industry has dramatically augmented the nitrogen flow by putting artificial fertilisers on the world market.

Today, the amount of industrial nitrogen fixation is on the same size scale as biological fixation. It is not surprising to find that nitrous compounds have become so abundant that they have accumulated in natural ecosystems, not least in recipient aquatic systems, such as the Baltic Sea, resulting in eutrophication, algal growth and dead sea bottoms.

3.8 The phosphorus and sulphur cycles

Phosphorus is another element essential to living cells. Phosphorus is common in soil and minerals, and the cycle begins when phosphorus is released from soil through weathering processes. Phosphorus as phosphate is dissolved in water and absorbed by plants and in this way enters biological forms. It returns to inorganic phosphate as the organisms decay.

Phosphorous has no atmospheric form and it is thus directly transferred by water, mostly bound to fine particles in surface water where it is trapped in sediments and in this way returns to the lithosphere.

The phosphorous cycle is a very slow one. Man, however, dramatically speeds it up when phosphorus is mined, e.g. as phosphorites. Some of the richest phosphorite mines in the world are found in Estonia and in Northern Russia in the Murmansk region. The large amounts of phosphorous used as fertilisers in agriculture also add to eutrophication of surface waters, especially in lakes.

Sulphur is a common element in many minerals and thus part of the lithosphere. It is released in weathering processes and dissolved in various forms in water. As such it is taken up by plants and bacteria and incorporated in several kinds of bio-molecules. It is essential for all life forms. Sulphur has a complex chemistry and is available both as a dissolved substance in water, and in a gaseous form in the atmosphere. It has a capacity to form aerosols and droplets in air. Dimethylsulphide (DMS), formed by certain algae in the seas seems to have a role in climate regulation. DMS initiate aerosol formation and later droplets, which add to the albedo of the atmosphere above the oceans. Since it is formed when the water is warmer, it thus counteracts a temperature increase.

Sulphur is added to the atmosphere by volcanic activities. In the atmosphere, it is naturally oxidised to become sulphuric acid, a strong acid that is efficiently acidifying the water or soil where it finally precipitates. It is returned to the lithosphere as sediments.

Man has dramatically increased sulphur flow by burning fossil fuels, which often contain several percent sulphur. Again these artificial flows equal the natural flows.

3.9 How society interacts with natural flows

The societal physical influence on nature is characterized by two different types of interaction: exchange of energy and materials and by manipulation of nature. Exchange of energy has two sides: exchange takes place in the form of

- extraction of resources, energy and matter from nature and
- emissions (return flows) of energy and matter into nature.

Human society uses exergy and matter from the ecosphere and lithosphere to compensate for losses, to maintain processes and to build up new structures within the material side of so-ciety, which we shall here call the technosphere. Manipulation comprises various material rearrangements within nature, that is, influences which do not imply an exchange of materials with the technosphere.

The resources extracted, that is, specific materials or flows in nature in a concentrated form, can be characterised according to their sources and renewability: resources are extracted from natural flows, funds and deposits for use in the society.

- Natural flows are continuously flowing materials and energy fluxes ultimately driven by the exergy flows (for example, sunlight and winds) coming into the ecosphere. If not used, they are eventually dissipated naturally.
- The stocksare pools of materials accumulated and regenerated with the help of natural flows (for example, forests, fish populations, clean air and water). Their capacity for regeneration gives an absolute potential for the long-run rate of extraction.
- The deposits are pools of materials (for example, minerals and ores)with such long re-generation rates, if any, that they are gradually depleted as extracted.

This applies to the lithospheric deposits accumulated on geological time-scales. However, some ecospheric pools also have long turnover times compared to society. For example, peat accumulated since the latest ice age ten thousand years ago may in this perspective be considered as a non-renewable stock.

The extraction of renewable resources involves impacts on resources which may severely limit possible sustainable extraction rates far below the limit set solely by regeneration capacity. Hydro-power schemes can change water flows and influence ecosystems along a whole river and harvesting in forests may shift the composition and the frequency of old, but ecologically important, trees.

Extracted materials that are not stored or accumulated in the technosphere are returned to nature, in accordance with the law of conservation of matter. The capacity of the ecosphere to degrade, remove or assimilate these flows in the cycles of nature depends on the type of flow. There are, as with resources, flow capacities which can manage a certain rate. For example, there is the capacity of a water body to decompose organic materials or to transfer materials to sediments out of reach for important life processes or stock capacities which are more characterized by limits on accumulated amounts that can be coped with without disturbing functioning: there is, for example, a limited capacity of soil to accumulate heavy metals and a limited capacity of the ecosphere to accumulate carbon.

The societal manipulation of nature includes:

- displacement of nature (societal activities force away or disturb ecological systems or geophysical functions by, for example, the construction of highways, etc.),
- reshaping the structures of nature (for example, the damming of rivers, ditching and ploughing) and

- guiding processes and flows (for example, in agricultural practices and the manipulation of genes).

Nature has a limited resource-creating capacity for the substances that society extracts as well as a limited assimilation capacity for the substances that society returns to nature. Furthermore, the stabilization capacity of nature is often reduced when it is manipulated, for example, through the loss of biodiversity.

Society also has an immaterial part, the human sphere. The technosphere with its structure and flows of materials and energy delivers certain services to the human sphere. These services are the immaterial part of resource use and, therefore, a service does not contain any material or energy. For example, an electric heater in an apartment gives an energy flow which is then leaked to the surroundings. The service provided in this process is a certain indoor climate. It is possible to increase the service flow without increasing the exchange of matter and energy with nature, by increasing the efficiency of the internal physical flows within the technosphere, that is, more service can be delivered per unit of exchange with nature.

We should also not forget that nature itself is delivering services more or less directly to the human sphere with negligible physical interaction involved when, for example, we enjoy beautiful scenery, feel pleasure from the sole existence of various species, and learn from nature.

It is possible to define more or less exactly the rules according to which the natural resources have to be managed to be sustained in the long-term. These are the so-called physical conditions for Sustainable Development. They are:

1. Substances extracted from the lithosphere must not systematically accumulate in the ecosphere.
2. Human-made substances must not systematically accumulate in the ecosphere.
3. The physical conditions for production and diversity within the ecosphere must not systematically be deteriorated.
4. The use of resources must be efficient and just with respect to meeting human needs.

It is easy to point to how these principles are not respected in our modern society. Principle 1 is violated as carbon dioxide is accumulating in the atmosphere when we extract and use fossil carbon. Principle 2 is violated when human made substances such as Polychlorinated Biphenyls accumulate in the biosphere. Principle 3 is violated as ecosystems are destroyed causing desertification for example in tropical forests, and Principle 4 is violated as large numbers of the human family are poor and needy while others are immensely rich.

In the same way we may point to how to improve the situation by listing the biological conditions for Sustainable Development. They are:

1. For sustainability, ecosystems dispose of wastes and replenish nutrients by recycling all elements.
2. For sustainability, ecosystems use sunlight as their source of energy.
3. For sustainability, the size of consumer populations are maintained so that overgrazing or over-use does not occur.
4. For sustainability, biodiversity is maintained.

This is the lesson we have to learn from Nature.

Chapter 3 sources:

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II
Resource Flows and Limits to Growth

Chapter 4
Limits to growth

4.1 The beginning – the Club of Rome

The economic societal system is sustainable as long as the environment may be considered as being in a steady state. The society has to operate within the boundaries of a global ecosystem which has – very definitely – a finite capacity to supply resources and to absorb the discharges. The same argument holds for the full variety of services that are offered by the ecosphere in providing clean air, good quality and quantity of water, clean and usable top soil and sustainable conditions for agricultural and industrial production, transportation and living. The sustainability scenario also has to affect the economical and the administrative systems which should be considered as subsets of the total natural system in which humanity dwells together with other species.

It is important that the natural resources utilized for the society are restricted to magnitudes that do not over-burden the environment. "Ecology worries about resource flows, since these are what contribute to environmental impacts" (Spangenberg et al, 1997). It is conceivable that the natural systems can pass a critical point where they will break down and fail to support what they have supported in the past. The world population is growing and the total physical activities of that population is growing even more.

These were the concerns of a small international group of professionals from the fields of diplomacy, industry, academia and civil society which met in April 1968 at a quiet villa in Rome, Italy invited by Italian industrialist Aurelio Peccei and Scottish scientist Alexander King. They came together to discuss the dilemma of prevailing short-term thinking in international affairs and, in particular, the concerns regarding unlimited resource consumption in an increasingly interdependent world. This was the birth of the famous Club of Rome, a society of 100 members very active up to this day.

Each participant in the meeting agreed to spend the next year raising the awareness of world leaders and major decision-makers on the crucial global issues of the future. They wanted to offer a new approach in doing this, focusing on the long-term consequences of growing global interdependence.

However at that meeting they did not know how to study the question of world development. The answer came when the Club of Rome members in 1969 met with Professor Jay Forrester from the Massachusetts Institute of Technology (MIT), Cambridge, USA. He had by then spent years to develop a computer method to study the complex urban development. He immediately recognized that his method – system dynamics – could be adapted to study also the development of the world, and agreed to carry out such a study.

4.2 System dynamics and the World3 model

System dynamics is an approach to understanding the behaviour of complex systems over time. It includes internal feedback loops between the elements of the system and time delays that affect the behaviour of the entire system. System dynamics is thus a mathematical modelling technique for framing, understanding, and discussing complex issues and problems. The feedback loops and stocks and flows of the system explains how even seemingly simple systems display nonlinearity and often surprising behaviour. System Dynamics models solve the problem of simultaneity (mutual causation) by updating all variables in small time increments with positive and negative feedbacks and time delays structuring the interactions and control.

When the group at MIT worked on system dynamics in 1970 there were no commercial software. Everything had to be developed from first principles as described by Forrester. And even then big main frame computers were used, and running the simulation model over a period of many years required many days of machine time. Today the same models can without problems be run on an ordinary laptop computer. Convenient system dynamics software were finally developed into user friendly versions in the 1990s and have since been applied to diverse systems.

Supported by the Club of Rome Forrester organised a group of very young scientists at his laboratory at MIT led by the Dennis Meadows. In the team was his wife Donella (Dana) Meadows, later famous for her writing, and among others the Norwegian economist student Jörgen Randers and US biologist Bill Behrens. In the end more than 60 scientists became part of the team. They collected global statistics in a number of areas, including population growth, economic development, pollution, industrial production, human welfare, food production etc. All data were collected in a model which was called World3. The Model consisted of a great number of elements which all were linked by some 40 differential equations.

The output was studied as five parameters: Resources, population, pollution, food per capita, and industrial output per capita. The model was run for a period of 200 years, from about 1900 to 2100, by incremental steps. The period from 1900-1970, with known data, was used to adjust the parameters. The model was then run for the following period up to year 2100 to study the world development under different assumptions.

The World3 computer model is complex, but its basic structure is not difficult to understand. World3 keeps track of stocks such as population, industrial capital, persistent pollution, and cultivated land. In the model, those stocks change through flows such as births and deaths; investment and depreciation; pollution generation and pollution assimilation; land erosion, land development, and land removed for urban and industrial uses.

The model accounts for positive and negative feedback loops that can radically affect the outcome of various scenarios. It also develops nonlinear relationships. For example, as more land is made arable, what's left is drier, or steeper, or has thinner soils. The cost of coping with these problems dramatically raises the cost of developing the land - a nonlinear relationship.

Feedback loops and nonlinear relationships make World3 dynamically complex, but the model is still a simplification of reality. World3 does not distinguish among different geographic parts of the world, nor does it represent separately the rich and the poor. It keeps track of only two aggregate pollutants, which move through and affect the environment in ways that are typical of the hundreds of pollutants the economy actually emits. It omits the causes and consequences of violence. And there is no military capital or corruption explicitly represented in World3. Incorporating those many distinctions, however, would not necessarily make the model better. And it would make it very much harder to comprehend. This probably makes World3 highly optimistic. It has no military sector to drain capital and resources from the productive economy. It has no wars to kill people, destroy capital, waste lands, or generate pollution. It has no ethnic strife, no corruption, no floods, earthquakes, nuclear accidents, or AIDS epidemics. The model represents the uppermost possibilities for the "real" world.

The authors developed World3 to understand the broad sweep of the future—the possible behavior patterns, through which the human economy will interact with the carrying capacity of the planet over the coming century.

World3's core question is: How may the expanding global population and materials economy interact with and adapt to the earth's limited carrying capacity over the coming decades? The model does not make predictions, but rather is a tool to understand the broad sweeps and the behavioral tendencies of the system.

4.3 The 1972 Limits to Growth

The result of the work was published in a small book called Limits to Growth on March 1st 1972. It was labelled the first report to the Club of Rome. The originality of their approach soon became clear. In 1972 the campaigning of this growing group of like-minded individuals gained a new worldwide reputation. The Report explored a number of scenarios and stressed the choices open to society to reconcile sustainable progress within environmental constraints.

It was clear that up to the time of 1970 most parameters had been growing exponentially. This is obviously not possible to continue for a long time period. For more than a century, the world had been experiencing exponential growth in a number of areas, including population and industrial production. Positive feedback loops can reinforce and sustain exponential growth.

The 1972 The Limits to Growth study did as expected forecast that exponential growth would lead to economic collapse during the 21st century under a wide variety of growth scenarios. It says:

"If the present growth trends in world population, industrialisation, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity."

They explored a great number of different scenarios and their complexities. They wrote:

"In this first simple world model, we are interested only in the broad behavior modes of the population-capital system. By behavior modes we mean the tendencies of the variables in the system (population or pollution, for example) to change as time progresses. A variable may increase, decrease, remain constant, oscillate, or combine several of these characteristic modes. For ex-

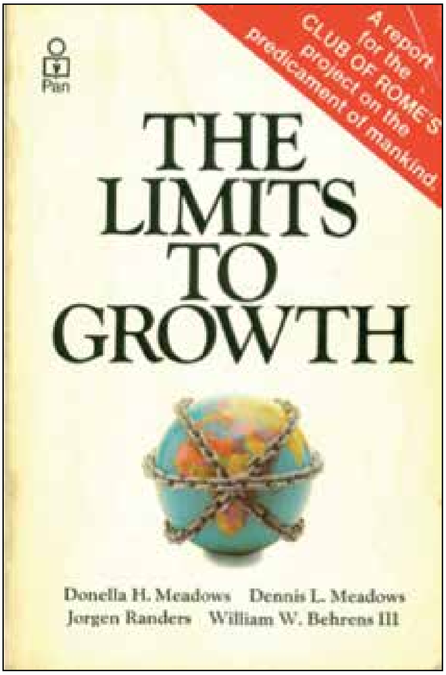


Figure 4.1. Limits to growth, 1972

ample, a population growing in a limited environment can approach the ultimate carrying capacity of that environment in several possible ways. It can adjust smoothly to an equilibrium below the environmental limit by means of a gradual decrease in growth rate, as shown below. It can overshoot the limit and then die back again in either a smooth or an oscillatory way, also as shown below. Or it can overshoot the limit and in the process decrease the ultimate carrying capacity by consuming some necessary nonrenewable resource, as diagrammed below. This behavior has been noted in many natural systems. For instance, deer or goats, when natural enemies are absent, often overgraze their range and cause erosion or destruction of the vegetation.

Table 4.1. Doubling times. A quantity growing according to a pure exponential growth equation doubles in a constant time period. There is a simple relationship between the rate of growth in percentage terms and the time it will take a quantity to double.

Growth Rate (% per year)	Approximate Doubling Times (Years)
0.1	720
0.5	144
1.0	72
2.0	36
3.0	24
4.0	18
5.0	14
6.0	12
7.0	10
10.0	7

Figure 4.2 top and bottom shows two of these scenarios. Figure 4.2 top shows the so-called business as usual, that is when economic development, extraction of resources etc. continue along the existing, often exponential, trends. Then an overshoot (extraction of resources is larger than the replacement rate) will happen and after a while we will have a peak and decline. This decline will occur sometimes in the middle of the 21st century. Figure 4.2 bottom shows the development assuming that resources are unlimited. The pollution will then set the limit, that is, the adsorptive capacity of the environment is limited, and we will have the same result. A main result of the study is that pollution control is the most urgent measure. (Compare today the "pollution" of the atmosphere with carbon dioxide as the most urgent issue to address).

The Limits to Growth had demonstrated the contradiction of unlimited and unrestrained growth in material consumption in a finite world had brought the issue to the top of the global agenda. The international effects of this publication in the fields of politics, economics and science was tremendous. With its focus on long-term vision and provocative scenarios, the report sold more than 12 million copies in some 35 languages worldwide.

The authors write in the report:

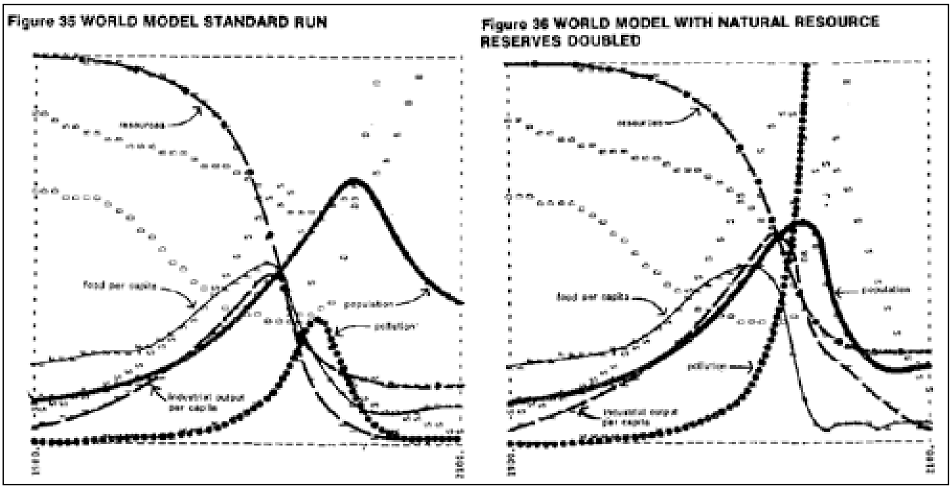


Figure 4.2 The Limits to Growth. During 1970-72 a research team under the leadership of Professor Dennis Meadow on the commission of the Club of Rome studied the long-term development of the Earth and human society. They constructed the so-called "World Model" consisting of some 40 differential equations relating parameters such as resources to each other. The model was fed with real data for 1900-1970, and then run for the period 1900 to 2100, under varying assumptions using systems dynamics methods. The conclusions were alarming. Above we see the result of the so-called standard run (development along existing trends). Here resources are depleted and pollution increasing dramatically around 2050. As a result productivity (food per capita) and population collapses. In another run resources were assumed to be unlimited (below). Then pollution increases even faster and productivity and population collapse faster. A main result of the study is that pollution control is the most urgent measure. (Meadows et al., 1972.)

"We are searching for a model output that represents a world system that is 1. Sustainable without sudden and uncontrollable collapse; and 2. Capable of satisfying the basic material requirements of all of its people."

Such an outcome would require that the global society would have start controlling pollution, reducing environmental impact and limit extraction of resources. They thought that this - considering the alternative collapse scenario - would obviously be the result, but it was not at all the case.

After publication many economists, scientists and political figures criticized the Limits to Growth, even making it ridiculous. They attacked the methodology, the computer, the conclusions, the rhetoric and the people behind the project. Especially economists from the developing countries saw the report as an attack on their possibilities to develop economically. Yale economist Henry C. Wallich agreed that growth could not continue indefinitely, but that a natural end to growth was preferable to intervention. Wallich stated that technology could solve all the problems the Meadows were concerned about, but only if growth continued apace. By stopping growth too soon, Wallich warned, the world would be "consigning billions to permanent poverty".

Thus when The Limits to Growth was published in 1972, economists, along with many industrialists, politicians, and Third World advocates raised their voices in outrage at the suggestion that population growth and material consumption need to be reduced by deliberate means. But nothing that has happened in the last 40 years has invalidated the book's warnings.

4.4 1992 and 2002 – 20 and 30 years updates

The World3 scenarios showed how population growth and natural resource use interacted to impose limits to industrial growth, a novel and even controversial idea at the time. In 1972, however, the world's population and economy were still comfortably within the planet's carrying capacity. The team found that there was still room to grow safely while we could examine longer-term options.

In 1992, this was no longer true. On the 20th anniversary of the publication of Limits to Growth, the team updated Limits in a book called Beyond the Limits. Already in the 1990s there was compelling evidence that humanity was moving deeper into unsustainable territory. Beyond the Limits argued that in many areas we had "overshot" our limits, or expanded our demands on the planet's resources and sinks beyond what could be sustained over time. The main challenge identified in Beyond the Limits was how to move the world back into sustainable territory.

In 2002 a new more careful study was conducted and the results published in Limits to Growth: The 30-Year Update, The authors had produced a comprehensive update to the original Limits, in which they conclude that humanity is dangerously in a state of overshoot. In 2003 the authors were far more pessimistic than they were in 1972. Humanity has

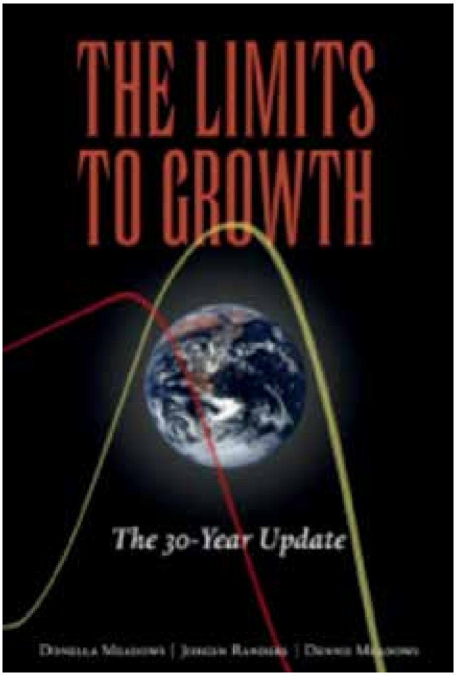


Figure 4.3. The Limits to Growth – The 30-year Update. Meadows et al.

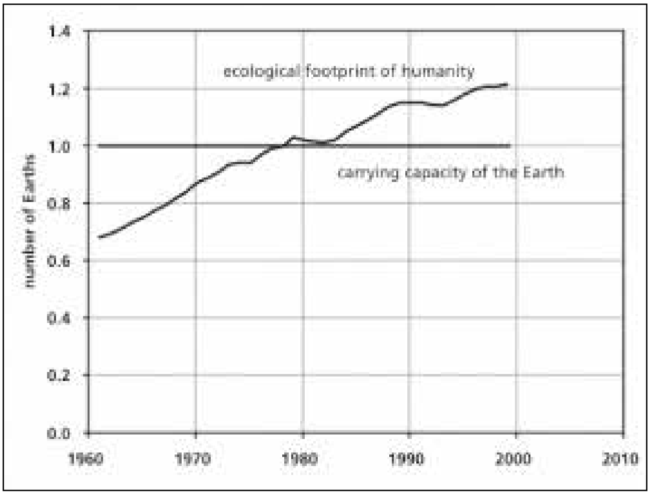


Figure 4.4. This graph shows the number of Earths required to provide the resources used by humanity and to absorb their emissions for each year since 1960. This human demand is compared with the available supply: Our one planet Earth. Human demand exceeds nature's supply from the 1980s onward, overshooting it by some 20% in 1999. (Source: M. Wackernagel et al.)

squandered the opportunity to correct our current course over the last 30 years, they conclude, and much must change if the world is to avoid the serious consequences of overshoot in the 21st century.

Many were amazed how precise the model had worked. The existing trends in 2002 were very close to what the model had predicted for the business as usual scenario. In 2002 then a new system dynamics study was then made with an expanded World3 model with much more and better statistics, and of course with dramatically enlarged computer capacity. The clear difference compared to the 1972 study was that the peak and collapse came closer, rather around 2025 than 2050, although obviously the peak and collapse would be different for different parameters and different parts of the world, so figures are not precise, rather symbolic.

Energy economist Matthew Simmons wrote, "The most amazing aspect of the book is how accurate many of the basic trend extrapolations … still are some 30 years later." "For example, the gap between rich and poor has only grown wider in the past three decades. Thirty years ago, it seemed unimaginable that humanity could expand its numbers and economy enough to alter the Earth's natural systems. But experience with the global climate system and the stratospheric ozone layer have proved them wrong."

"All the environmental and economic problems discussed in Limits to Growth had been treated at length during the 30 years which had passed and were well known. What made Limits to Growth: The 30-Year Update unique, however, is that it presents the underlying economic structure that leads to these problems. Moreover, Limits is a valuable reference and compilation of data. The authors include 80 tables and graphs that give a comprehensive, coherent view of many problems. The book will undoubtedly be used as a text in many courses at the college level, as its two earlier versions have been."

Using the World3 computer model, Limits to Growth: The 30-Year Update presents 10 different scenarios for the future, through the year 2100. In each scenario a few numbers are changed to test different estimates of "real world" parameters, or to incorporate optimistic predictions about the development of technology, or to see what happens if the world chooses different policies, ethics, or goals. Most of the scenarios presented in Limits result in overshoot and collapse - through depletion of resources, food shortages, industrial decline, or some combination of these or other factors.

Under the "business as usual scenario," world society proceeds in a traditional manner without major deviation from the policies pursued during most of the 20th century. In this scenario, society proceeds as long as possible without major policy change. Population rises to more than seven billion by 2030. But a few decades into the 21st century, growth of the economy stops and reverses abruptly.

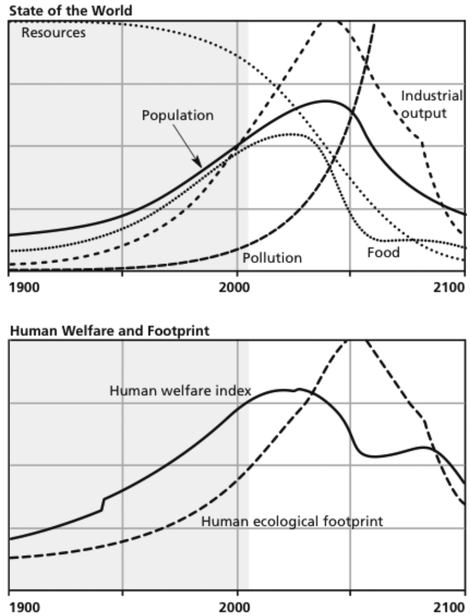
As natural resources become harder to obtain, capital is diverted to extracting more of them. This leaves less capital for investment in industrial output. The result is industrial decline, which forces declines in the service and agricultural sectors. About the year 2030, population peaks and begins to decrease as the death rate is driven upward by lack of food and health services.

A similar scenario assumes that the world's endowment of natural resources doubles, and further postulates that advances in resource extraction technologies are capable of postponing the onset of increasing extraction costs. Under this scenario industry can grow 20 years longer. But pollution levels soar, depressing land yields and requiring huge investments in agricultural recovery. The population finally declines because of food shortages and negative health effects from pollution.

Other scenarios address the problems of pollution and food shortages by assuming more effective pollution control technologies, land enhancement (an increase in the food yield per unit of land), and protections against soil erosion.

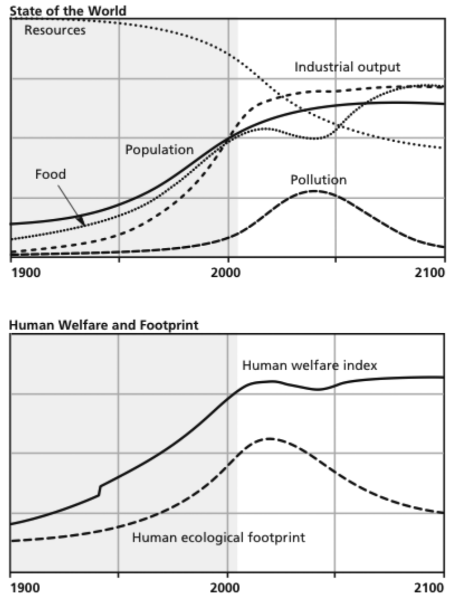
Even a scenario with these features however, results in overshoot and collapse. After 2070 the costs of the various technologies, plus the rising costs of obtaining nonrenewable resources from increasingly depleted mines, demand more capital than the economy can provide. The result is a rather abrupt decline.

The most common criticisms of the original World3 model were that it underestimated the power of technology and that it did not represent adequately the adaptive resilience of the free market. But technological advance and the market



Scenario 2: More Abundant Nonrenewable Resources

This table postulates that advances in resource extraction technologies are capable of postponing the onset of increasing extraction costs. Industry can grow 20 years longer. Population peaks at 8 billion in 2040, at much higher consumption levels. But pollution levels soar (outside the graph!), depressing land yields and requiring huge investments in agricultural recovery. The population finally declines because of food shortages and negative health effects from pollution.



Scenario 9: World Seeks Stable Population and Stable Industrial Output per Person, and Adds Pollution, Resource, and Agricultural technologies from 2002

In this scenario population and industrial output are limited, and in addition technologies are added to abate pollution, conserve resources, increase land yield, and protect agricultural land. The resulting society is sustainable: Nearly 8 billion people live with high human welfare and a continuously declining ecological footprint.

Figure 4.5. State of the world. human welfare and footprint. (Source: Limits to growth.)

are reflected in the model in many ways. The authors assume in World3 that markets function to allocate limited investment capital among competing needs, essentially without delay. Some technical improvements are built into the model, such as birth control, resource substitution, and the green revolution in agriculture. But even with the most effective technologies and the greatest economic resilience that seems possible, if those are the only changes, the model tends to generate scenarios of collapse.

One reason technology and markets are unlikely to prevent overshoot and collapse is that technology and markets are merely tools to serve goals of society as a whole. If society's implicit goals are to exploit nature, enrich the elites, and ignore the long term, then society will develop technologies and markets that destroy the environment, widen the gap between rich and poor, and optimize for short-term gain. In short, society develops technologies and markets that hasten a collapse instead of preventing it.

The second reason for the vulnerability of technology is that adjustment mechanisms have costs. The costs of technology and the market are reckoned in resources, energy, money, labor, and capital.

4.5 Limits to Growth 40 years – 2012

The 2012 occasion of 40 years of the publication of the original Limits to Growth was celebrated by a seminar organised by the Club of Rome at the Smithsonian Institute at Washington DC on March 1st, 2012. A new follow up study by the MIT team was not made, but at the meeting Jörgen Randers, one of the original authors of LTG, released his own book 2052 – A Global Forecast for the Next Forty Years. He had worked on this book at Norwegian Business School in Oslo where he was a professor and used system dynamics methods. He had also invited quite many of his colleagues from all over the world to contribute with their view of the development the coming 40 years. The book is thus a collection of views of the future, some optimistic, some much more pessimistic.

The results from the "2052" study are partly different from the scenarios of the 30-year LTG update. For example Randers predicts the global population to peak at 2040 about. The global economy will increase and double up to 2052. Global energy use will reach a peak by 2030, as energy efficiency is growing also greenhouse gas emissions will increase and not peak until 2030. As a consequence it will not be possible to stop global warming at 2 ^{o}C as today's policy requests. The difficult question is how the methane release from the Arctic will develop. If this turns out to be large the climate effect may get out of hand.

All data from the "2052" book are available at www.2052.org.

Dennis Meadows have continued to explain the basic result of the Limits to Growth study for the general public, for students, researchers and politicians. In a lecture at 2009 he said the following (from the summary of the talk by Gail Tverberg):

"40 years ago I worked with others at Massachusetts Institute of Technology to build a simple computer model that might offer some insight into the impact of limits to growth. We did not expect the model to be predictive - only that the scenarios might provide a rough boundaries regarding what might happen in the

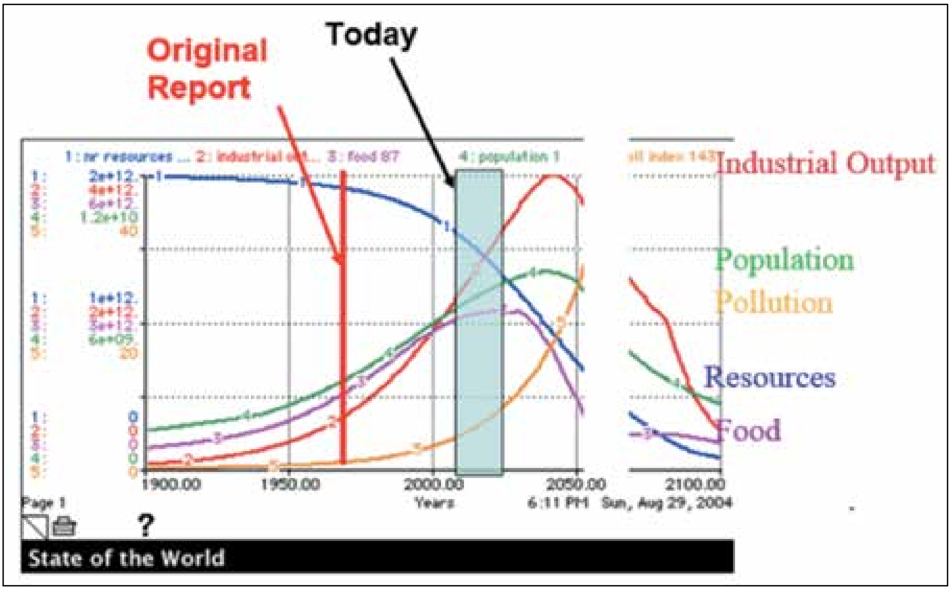


Figure 4.6. State of the world – 40 years update.

future. Let's look at our reference scenario (Picture). The red line shows where we were when the model was first developed. The area shaded in light blue represents the time period that might be changed by the policies we implement today.

In 1972, we expected another 40 to 80 years of growth in the various scenarios. The major difference I see in looking at the situation now is that things seem to be developing more rapidly than we expected then. While some of the scenarios we looked at ended in orderly decline, most of the scenarios we modelled ended in collapse. Many assume that technology may change things, but it does not avoid the end of growth or the decline. When we put together models using phenomenally optimistic assumptions, it just moved the decline date back a few years. Social changes are essential for a better outcome.

A key factor to understand is that what are normally considered problems today - for example, climate change, energy shortages, and erosion - aren't really problems. Instead, they are symptoms of attempted infinite growth in a finite world. In some ways, the situation is like if you have a friend who has cancer, and because of the cancer he has a headache. It is not nice to have a headache, so you give your friend pain relievers, but you don't imagine you have cured the problem. The problem is cancer, and until you deal with the problem, there will be one or another manifestation, such as a head ache.

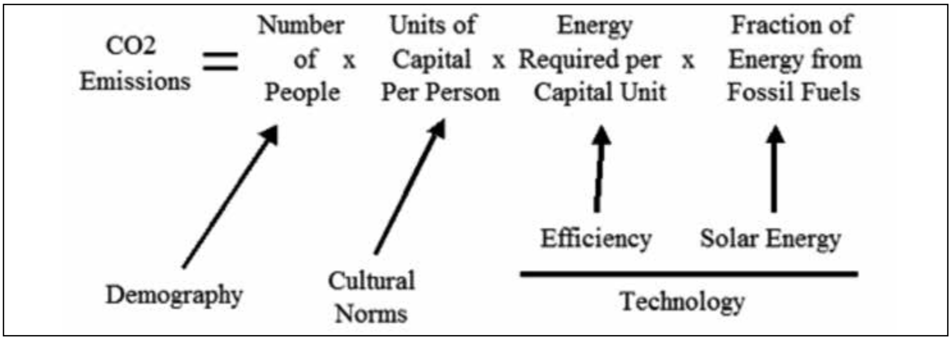


Figure 4.7. State of the world – The model equation.

We talk a lot about climate change today. I predict that in three or four years, we won't be talking about climate change. We will be talking about energy scarcity or food shortages or declining water supplies. This will occur not because we have dealt with climate, but because it is one of a large family of pressures which are going to mount until finally physical growth stops.

In the early days, we had only models to tell us we were beyond carrying capacity. Now, we can look at the newspapers and get confirmation of the fact. It was astonishing to me in 1972 that people could believe that there are no limits. Initially, we assumed that people were just uninformed. If we can manage to give them the facts, they will change their opinion. Nothing I have seen in 40 years gives me support for that opinion. There are an infinite number of objections, so you are never going to come to the end of the process.

Let me discuss some key assumptions in our model. There are three different ways we use space - one for extraction; one for activity; and one for basically dumping stuff. The first and third of these have costs associated with them. When you have 100% of a given resource, you can start to use it up, and you don't perceive any particular cost increase. It is only when you get past maybe 50%, 60% depletion that you start to see a radical rises in cost of extraction. There is an analogous curve for dumps, where we try to put stuff. As the fraction of the sink is slowly occupied to a greater and greater extent, the cost of dealing with the consequences of production goes up rapidly.

Industrial growth occurs because more capital gives you more output; more output permits more investment; and more investment let you build up your capital stock. As long as investment exceeds depreciation, you have growth - exponential growth - and rapid rates of increase. Depending on how equitable society is, people, at least some people, get richer.

However, as we start to draw down our resources and fill up our sinks, more and more of the capital has to be drawn off to provide for the other needs. Eventually, you get to the point where you can't sustain production around the industrial capital loop sufficiently to sustain growth.

In our world model, it is the failure to produce enough output for capital reinvestment that tips you over into decline. We are now moving into that period.

Some people now looking at our curves would imagine that the periods of greatest stress would be after the peak--once the declines have set in. I don't think that is true. Right now, around the globe, we (that is corporate, political, and religious leaders) are working as hard as we can to sustain growth. For growth to stop, negative pressure has to mount until they are strong enough to offset our positive pressures. That's the period that we are in now. So I anticipate the big stresses are the ones we are going to encounter over the next couple of decades.

Let me give one very quick example. CO_2 concentration in the atmosphere has increased at accelerating speed since our book came out. Why? Everyone in the world wants greenhouse gases to go down, but, by and large, they keep going up. The CO_2 emissions are a function of four factors: 1. Number of people; 2. Number of units of capital per person, which is a surrogate for living standards; 3. The amount of energy required to build and operate that capital; 4. The fraction of that energy that comes from non-fossil sources.

So far, our concern about climate change had manifested itself through efforts to improve efficiency and to implement alternative energy sources -- the so-called technology options. But as long as we ignore demographic and cultural issues, the growth in the first two factors will continue to offset all of the improvement we make in factors 3 and 4. And so until we can understand how to begin reducing the growth in the first two factors, climate change will continue."

4.6 Transitions to a sustainable world

The world can respond in three ways to signals that resource use and pollution emissions have gone beyond their sustainable limits. One way is to disguise, deny, or confuse the signals. Generally this takes the form of efforts to shift costs to those who are far away in space and time. An example would be to buy air conditioners for relief from a warming climate, or to ship toxic wastes for disposal in a distant region.

A second way is to alleviate the pressures from limits by employing technical or economic fixes. For example, reducing the amount of pollution generated per mile of driving or per kilowatt of electricity generated. These approaches, however, will not eliminate the causes of these pressures.

The third way is to work on the underlying causes, to recognize that the socioeconomic system has overshot its limits, is headed toward collapse, and therefore seek to change the structure of the system. World3 can be used to test some of the simplest changes that might result from a society that decides to back down from overshoot and pursue goals more satisfying and sustainable than perpetual material growth.

There are many thoughts about what steps towards a more sustainable society would look like. Some people think that a sustainable society would have to stop using nonrenewable resources. But that is an over-rigid interpretation of what it means to be sustainable. Certainly a sustainable society would use nonrenewable gifts from the earth's crust more thoughtfully and efficiently.

The authors to the limits to growth suggest a few general guidelines for what sustainability would look like, and what steps we should take to get there:

- Extend the planning horizon. Base the choice among current options much more on their long-term costs and benefits. Today we suffer from "short-termism". Companies think about their near future, even the coming months, and politicians about the next election. But that is too short a time frame when discussion the limits to growth.
- Improve the signals. Learn more about the real welfare of human population and the real impact on the world ecosystem of human activity.
- Speed up response time. Look actively for signals that indicate when the environment or society is stressed. Decide in advance what to do if problems appear.
- Minimize the use of nonrenewable resources.
- Prevent the erosion of renewable resources.
- Use all resources with maximum efficiency.
- Slow and eventually stop exponential growth of population and physical capital.

The necessity of taking the industrial world to its next stage of evolution is not a disaster – it is an amazing opportunity. How to seize the opportunity, how to bring into being a world that is not only sustainable, functional, and equitable but also deeply desirable is a question of leadership and ethics and vision and courage, properties not of computer models but of the human heart and soul.

Sustainability does not mean zero growth. Rather, a sustainable society would be interested in qualitative development, not physical expansion. It would use material growth as a considered tool, not a perpetual mandate. Neither for nor against growth, it would begin to discriminate among kinds of growth and purposes for growth. It would ask what the growth is for, and who would benefit, and what it would cost, and how long it would last, and whether the growth could be accommodated by the sources and sinks of the earth.

The question of how to create a sustainable future is the most urgent to find answers to for anyone who has been confronted with the results of the Limits to Growth studies. This is discussed at some length in the movie "The Last Call" released in 2013 by the Italian producer Enrico Cerasuolo (http://www.lastcallthefilm.org/). Here the researchers of the Limits to Growth study give their points of view.

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Chapter 5
The planetary boundaries

5.1 The Anthropocene

Human activities increasingly influence the Earth's climate and ecosystems. The scale of this influence is so large, that many scientists consider the impact of human society of geological dimensions, it is the dominating force that shape the earth system. For that reason they have started to talk about the recent period in the history of Earth as the Anthropocene (from the Greek word for human: anthropo) in parallel to names of earlier periods such as the Holocene or the Pleistocene, which together makes up the Quaternary.

Already in the 1960s some Russian scientists started to use the term Anthropocene. The best know promoter of the concept, however, is the atmospheric chemist Paul Crutzen, well known and Nobel Prize winner for his contribution to understanding how the ozone layer is degraded by chemicals. He regards the influence of human behaviour on the Earth's atmosphere in recent centuries so significant as to constitute a new geological epoch. The term is so far not officially adopted by the geologists, and thus remains a way to point out the large-scale changes our planet Earth undergoes, most often counted from the beginning of industrialism, although some researchers count Anthropocene from the 1950s when the human impact builds up to the large scale we know today.

The concept of Anthropocene should be understood in relation to the relatively stable environment of the Holocene, the current interglacial period that began about 10 000 years ago, which allowed agriculture and complex societies, including the present, to develop and flourish (Fig. 5.1). That stability induced humans, for the first time, to invest in a major way in their natural environment rather than merely exploiting it. We have now become so dependent on those investments for our way of life, and how we have organized society, technologies, and economies around them, that we must take the range within which Earth System processes varied in the Holocene as a scientific reference point for a desirable planetary state.

Despite some natural environmental fluctuations over the past 10 000 years (e.g., rainfall patterns, vegetation distribution, and nitrogen cycling), Earth has

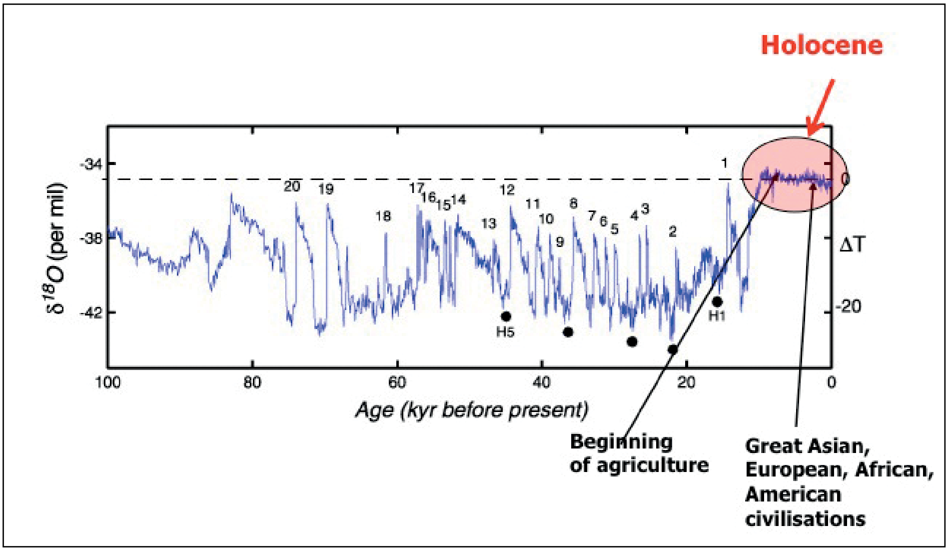

Figure 5.1 Temperature of the Earth the last 100 000 years measured as percent of the isotope ^{18}O. Source: Young and Steffen, 2009, Principles of Ecosystem Stewardship. (Source: http://www.stockholmresilience.org/21/research/research-programmes/planetary-boundaries/planetary-boundaries-data.html)

remained within the Holocene stability domain. The resilience of the planet has kept it within the range of variation associated with the Holocene state, with key biogeochemical and atmospheric parameters fluctuating within a relatively narrow range. At the same time, marked changes in regional system dynamics have occurred over that period. Although the imprint of early human activities can sometimes be seen at the regional scale, e.g., altered fire regimes and megafauna extinctions, there is no clear evidence that humans have affected the functioning of the Earth System at the global scale until very recently. However, since the industrial revolution, what we may call the advent of the Anthropocene, humans are effectively pushing the planet outside the Holocene range of variability for many key Earth System processes. Without such pressures, the Holocene state may be maintained for thousands of years into the future.

5.2 The planetary boundaries

Is the exponential growth of human activities so large that it could destabilize critical biophysical systems and trigger abrupt or irreversible environmental changes that would be deleterious or even catastrophic for human well-being? This is a profound dilemma because the predominant paradigm of social and economic development is largely ignoring the risk of human-induced environmental disasters at continental or planetary scales.

Based on these concerns a group of environmental researchers led by Johan Rockström from Stockholm Resilience Centre, Sweden and Will Steffen at the Australian National University undertook to identify which of the impacts on the Planetary System could risk to change Earth so much that it would become uninhabitable to human society as it is today. In 2009 a group of 28 researchers from all over the world, led by Rockström and Steffen published a paper to define a framework for planetary boundaries (Fig. 5.2). These are boundaries within which we need to stay to be sure to avoid environmental collapse – what they called "a safe operating space for humanity".

The authors identified the planetary boundaries as thresholds beyond which we risk to come to tipping points. Tipping points are situations where planetary environmental systems change irreversibly and abruptly to come to a new situation. In short, when we cross boundaries we risk the resilience of the system. Resilience means that the system has the capacity to return back to its original state after an impact. You may compare to a ball rolling around its lowest balancing point; if it is moved some distance and is left it will return back to its point of lowest energy. But if you take the ball over a higher threshold into a new "valley" it will stay there and not roll back to where it came from. It passed a tipping point.

The authors identified nine Earth systems processes which have such boundaries, which we should not cross to be on the safe side. For some of these processes a quantitative value is given for the boundary. For others we do not know enough to identify the boundary.

The nine planetary boundaries identified were:

- climate change
- stratospheric ozone
- land use change
- freshwater use
- biological diversity
- ocean acidification
- nitrogen and phosphorus inputs to the biosphere and oceans
- aerosol loading
- chemical pollution

The study suggests that three of these boundaries (climate change, biological diversity and nitrogen input to the biosphere) may already have been transgressed. In

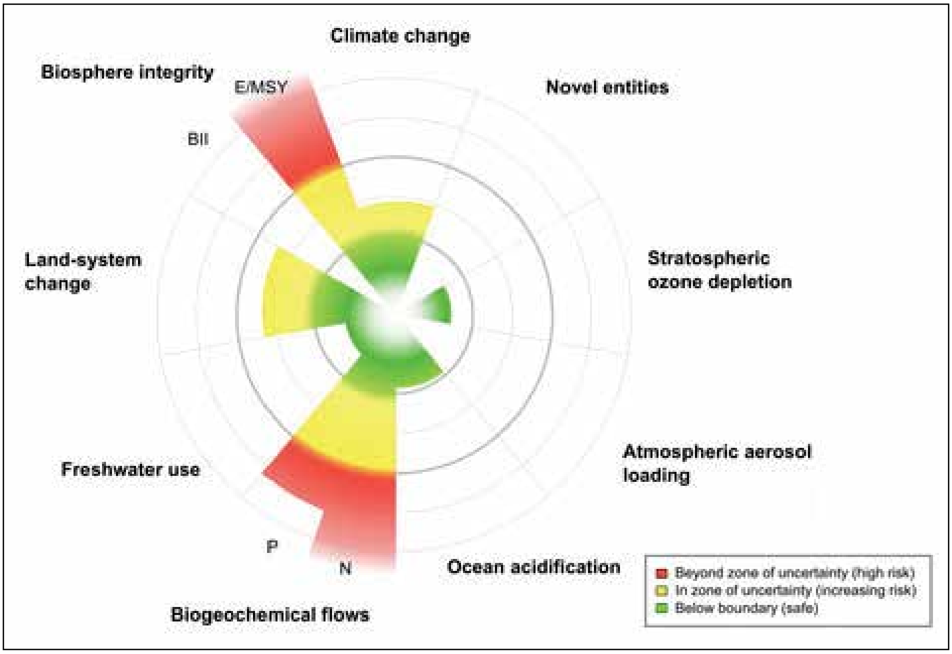

Figure 5.2 The planetary boundaries. (Source: Rockström et al. Planetary Boundaries: Exploring the Safe Operating Space for Humanity Ecology and Society 14(2): 32. and Steffen et. al, Science 16 January 2015. http://www.stockholmresilience.org/21/research/research-programmes/planetary-boundaries/planetary-boundaries-data.html)

addition, it emphasizes that the boundaries are strongly connected – crossing one boundary may seriously threaten the ability to stay within safe levels of the others.

So far, science has provided warnings of planetary risks of crossing thresholds in the areas of climate change and stratospheric ozone. However, the growing human pressure on the planet necessitates attention to other biophysical processes that are of significance to the resilience of sub-systems of Earth and the Earth System as a whole. Erosion of resilience manifests itself when long periods of seemingly stable conditions are followed by periods of abrupt, non-linear change, reflected in critical transitions from one stability domain to another when thresholds are crossed.

The Anthropocene raises a new question: "What are the non-negotiable planetary preconditions that humanity needs to respect in order to avoid the risk of deleterious or even catastrophic environmental change at continental or global scales?" Johan Rockström and colleagues made a first attempt at identifying planetary boundaries for key Earth System processes associated with dangerous thresholds, the crossing of which could push the planet out of the desired Holocene state.

5.3 Tipping towards the unknown

Thresholds are non-linear transitions in the functioning of coupled human–environmental systems. They are often amplified/caused by non-linear feedbacks. A clear example is the recent abrupt retreat of Arctic Sea summer ice caused by anthropogenic global warming. This retreat is amplified by the positive feedback caused by change in albedo (reflection of the sunlight) as the enlarged dark sea surface is adsorbing almost all light and heat, while the retreating white ice is reflecting almost 95%.

Some Earth System processes, such as land-use change, are not associated with known thresholds at the continental to global scale. Still they may through continuous decline of key ecological functions such as carbon sequestration, cause functional collapses, generating feedbacks that trigger or increase the likelihood of a global threshold in other processes such as climate change. Such processes may further trigger non-linear dynamics at lower scales, e.g., crossing of thresholds in lakes, forests, and savannahs, as a result of land-use change, water use, and nutrient loading. Such non-linear changes, from a desired to an undesired state, may become a global concern for humanity, if occurring across the planet.

Boundaries are human-determined values of the control variable – parameter indicating the boundary – set at a "safe" distance from a dangerous level or from its global threshold. Determining a safe distance involves normative judgments of how societies choose to deal with risk and uncertainty. The choice of control variable for each planetary boundary was based on the assessment of the variable that on balance may provide the most comprehensive, aggregated, and measurable parameter for individual boundaries.

There is much uncertainty in quantifying planetary boundaries. This is due to

- lack of scientific knowledge about the nature of the biophysical thresholds themselves
- intrinsic uncertainty of how complex systems behave
- ways in which other biophysical processes such as feedback mechanisms interact with the primary control variable
- uncertainty regarding the allowed time of overshoot of a critical control variable in the Earth System before a threshold is crossed.

This generates a zone of uncertainty around each threshold. The nature and size of that zone is critical in determining where to place the planetary boundary. The present values of the boundary positions correspond to the lower end of the uncertainty zone for each boundary. In addition each proposed boundary position assumes that no other boundaries are transgressed.

The planetary boundaries approach builds on and extends approaches based on limits-to-growth, safe minimum standards, the precautionary principle, and tolerable windows. A key advance is that the planetary boundaries approach focuses on the biophysical processes of the Earth System that determine the self-regulating capacity of the planet. It incorporates the role of thresholds related to large-scale Earth System processes, the crossing of which may trigger non-linear changes in the functioning of the Earth System, thereby challenging social–ecological resilience at regional to global scales.

We may here also mention the concept of Gaia, introduced by James Lovelock in the 1970s, which sees the planet as a self-regulating system.

Together, the set of boundaries represents the dynamic biophysical "space" of the Earth System within which humanity has evolved and thrived. The boundaries respect Earth's "rules of the game" or, as it were, define the "planetary playing field" for the human enterprise. The thresholds in key Earth System processes exist irrespective of peoples' preferences, values, or compromises based on political and socioeconomic feasibility, such as expectations of technological breakthroughs and fluctuations in economic growth.

5.4 Categorizing planetary boundaries

The nine planetary boundaries identified here cover

- the global biogeochemical cycles of nitrogen, phosphorus, carbon, and water;
- the major physical circulation systems of the planet (the climate, stratosphere, ocean systems);
- biophysical features of Earth that contribute to the underlying resilience of its self-regulatory capacity (marine and terrestrial biodiversity, land systems); and
- two critical features associated with anthropogenic global change, aerosol loading and chemical pollution.

There is enough scientific evidence to make a preliminary, first attempt at quantifying control variables for seven of these boundaries. The remaining two (aerosol loading and chemical pollution) should be included among the planetary boundaries, but we are as yet unable to suggest quantitative boundary levels.

We may distinguish between two categories of boundaries. The first are directly related to sharp continental or planetary thresholds, such as the risk of melting of the Greenland and Antarctic ice sheets when permanently crossing a threshold of radiative forcing (solar energy input). The second category are those based on "slow" planetary processes with no current evidence of planetary scale threshold behaviour, which provide the underlying resilience of the Earth System by functioning as sinks and sources of carbon and by regulating water, nutrient, and mineral fluxes.

There is ample evidence from local to regional-scale ecosystems, such as lakes, forests, and coral reefs, that gradual changes in certain key control variables, e.g., biodiversity, harvesting, soil quality, freshwater flows, and nutrient cycles, can trigger an abrupt system state change when critical thresholds have been crossed. Some planetary thresholds are driven by systemic global-scale processes, impacting sub-systems "top down", while others which arise at the local and regional scales, become a global concern at the aggregate level, if occurring in multiple locations simultaneously or where the gradual aggregate impacts may increase the likelihood of crossing planetary thresholds in other Earth System processes thus affecting the Earth System "bottom up".

Many planetary-scale processes, such as climate change, primarily produce impacts at a sub-Earth System scale. Climate change is associated with several sub-system "tipping elements", e.g., the Indian monsoon and El Niño event, which all show varying degrees of sensitivity to a change in radiative forcing or temperature rise.

5.5 Boundary 1 – Climate Change

The climate-change boundary is currently under vigorous discussion. There is a growing consensus toward a "2°C" approach. The agreement at the Copenhagen Climate Convention meeting in 2009, was to contain the rise in global mean temperature to no more than 2°C above the pre-industrial level. The consideration of this limit is based on a combination of analytical and political arguments. It needs to be emphasized, however, that significant risks of deleterious climate impacts for society and the environment have to be faced even if the 2°C line can be held, that is at a temperature rise below 2°C.

The climate-change boundary aims at minimizing the risk of highly non-linear, possibly abrupt and irreversible, Earth System responses related to one or more thresholds, the crossing of which could lead to the disruption of regional climates, trigger the collapse of major climate dynamics patterns such as the thermo-haline circulation (e.g. the Golf stream), and drive other impacts difficult for society to cope with, such as rapid sea-level rise.

The definition of the planetary boundary for climate change, use both atmospheric CO_2 concentration, 350 ppm CO_2, and radiative forcing, 1 W/m^2 above the pre-industrial level, as global-scale control variables. The boundary is based on (i) an analysis of the equilibrium sensitivity of the climate system to greenhouse gas forcing, (ii) the behaviour of the large polar ice sheets under climates warmer than those of the Holocene, and (iii) the observed behaviour of the climate system at a current CO_2 concentration.

Palaeo-climatic data from 65 million years ago to the present points to decreasing CO_2 concentration as the major factor in the long-term cooling trend over that period. The data further suggest that the planet was largely ice free until atmospheric CO_2 concentrations fell to 450 ppm (±100 ppm), indicating a danger zone when concentrations of CO_2 rise within the range of 350-550 ppm (Hansen et al. 2008). The above suggests that raising CO_2 concentration above 350 ppm may lead to crossing a threshold that results in the eventual disappearance of some of the large polar ice sheets, with a higher risk of crossing the threshold as the CO_2 concentration approaches the upper end of the range.

The contemporary climate is thus moving out of the envelope of Holocene variability, sharply increasing the risk of dangerous climate change. Observations of a climate transition include a rapid retreat of summer sea ice in the Arctic Ocean, retreat of mountain glaciers around the world, loss of mass from the Greenland and West Antarctic ice sheets, an increased rate of sea-level rise in the last 10-15 years, a 4° latitude pole-ward shift of subtropical regions, increased bleaching and mortality in coral reefs, a rise in the number of large floods, and the activation of slow feedback processes like the weakening of the oceanic carbon sink.

5.6 Boundary 2 – Ocean Acidification

Ocean acidification poses a challenge to marine biodiversity and the ability of oceans to continue to function as a sink of CO_2, currently removing roughly 25% of human emissions. The atmospheric removal process includes both dissolution of CO_2 into seawater, and the uptake of carbon by marine organisms.

Addition of CO_2 to the oceans increases the acidity (lowers pH) of the surface seawater. Many marine organisms are very sensitive to changes in ocean CO_2 chemistry—especially those biota that use carbonate ions dissolved in the seawater to form protective calcium carbonate shells or skeletal structures. Surface ocean pH has decreased by about 0.1 pH units (corresponding to a 30% increase in hydrogen ion concentration and a 16% decline in carbonate concentrations) since pre-industrial times. This rate of acidification is at least 100 times faster than at any other time in the last 20 million years.

Marine organisms secrete calcium carbonate primarily in the forms of aragonite by corals, many molluscs, and other marine life; calcite, by different single-celled plankton and other groups; and biogenic calcium carbonate, high magnesium calcite by some coralline red algae and sea urchins. For all three of these types of calcium carbonate, the carbonate ion concentration strongly affects the saturation state of the mineral in seawater. If the calcium carbonate saturation state is less than one, then calcium carbonate produced by marine organisms to make their solid shells becomes soluble.

Ocean acidification may have serious impacts on coral reefs and associated ecosystems. Coral reefs are in danger of being exposed to marginal conditions or extremely marginal conditions almost everywhere by as early as 2050, causing substantial changes in species composition and in the dynamics of coral and other reef communities. Similarly, marine plankton are also vulnerable, presumably with ripple effects up the food chain.

Although significant questions remain as to how far from a threshold the boundary value should be set, we propose a planetary boundary where oceanic aragonite saturation state is maintained at 80% or higher of the average global pre-industrial surface seawater to ensure adequate conditions for most coral systems.

5.7 Boundary 3 – Stratospheric Ozone Depletion

Stratospheric ozone filters ultraviolet radiation from the sun. The appearance of the Antarctic ozone hole was a textbook example of a threshold in the Earth System being crossed -completely unexpectedly. A combination of increased concentrations of anthropogenic ozone-depleting substances, like chlorofluorocarbons, and polar stratospheric clouds moved the Antarctic stratosphere into a new regime: one in which ozone effectively disappeared in the lower stratosphere in the region during the Austral spring. This thinning of the Austral polar stratospheric ozone layer has negative impacts on marine organisms and poses risks to human health. Although it does not appear that there is a similar threshold for global ozone, there is the possibility that global warming, which leads to a cooler stratosphere, could cause an increase in the formation of polar stratospheric clouds. Were this to happen in the Arctic region, it could trigger ozone holes over the northern hemisphere continents, with potential impacts on populations there.

The ozone hole "tipping point" depends on anthropogenic ozone-depleting substances, but also on sufficiently cold temperatures and a sufficient amount of water vapour and, in some cases, nitric acid. Humans contribute directly to the first (and to some extent the last) of these, and indirectly to the others. Polar ozone holes have local impacts, but a thinning of the extra-polar ozone layer would have a much larger impact on humans and ecosystems.

Fortunately, because of the actions taken as a result of the Montreal Protocol and its subsequent amendments, we appear to be on a path that avoids transgression of this boundary. In 2005, the tropospheric concentrations of ozone-depleting gases had decreased by 8%-9% from their peak values in 1992-1994. Although there is a considerable lag time between concentration decreases in the troposphere and stratospheric ozone recovery, at least the major anthropogenic driver of ozone depletion is being reduced. The case of stratospheric ozone is a good example where concerted human effort and wise decision making seem to have enabled us to stay within a planetary boundary.

5.8 Boundary 4 – Interference with Global Phosphorus and Nitrogen Cycles

Eutrophication due to human-induced influxes of nitrogen (N) and phosphorus (P) can push aquatic and marine systems across thresholds, generating abrupt non-linear change from, for example, a clear-water oligotrophic state to a turbid-water eutrophic state. Shifts between such alternate stable states depend on complex interactions between N and P flows and on the prevailing biogeochemical setting. Human-induced degradation of ecosystem states, e.g., overfishing, land degradation, and increase in N and P flows at regional to global scales may cause non-linear change in terrestrial, aquatic, and marine systems, while simultaneously functioning as a slow driver influencing anthropogenic climate change at the planetary level.

The reason to keep the N and P cycles as one boundary is primarily the close interactions between N and P as key biological nutrients in driving abrupt shifts in sub-systems of the Earth.

Human modification of the N cycle is profound. Human activities now convert more N2 from the atmosphere into reactive forms than all of the Earth's terrestrial processes combined. Human-driven conversion occurs primarily through four processes:

- industrial fixation of atmospheric N_2 to ammonia (~80 Mt N yr-1);
- agricultural fixation of atmospheric N_2 via cultivation of leguminous crops (~40 Mt N yr-1);
- fossil-fuel combustion (~20 Mt N yr-1);
- and biomass burning (~10 Mt N yr-1).

Although the primary purpose of most of this new reactive N is to enhance food production via fertilization, much reactive N eventually ends up in the environment polluting waterways and coastal zones, adding to the local and global pollution burden in the atmosphere, and accumulating in the biosphere. Efforts to limit N pollution have, to date, been undertaken at local and regional scales for example by limiting the concentration of nitrate in groundwater or the emission of nitric oxides to urban air.

In addition to the various forms of reactive N to the environment nitrous oxide is one of the most important greenhouse gases and thus acts as a systemic driver at the planetary scale.

Setting a planetary boundary is not straightforward. Today the boundary is initially set at approximately 25% of its current value, or to about 35 Mt N yr-1. Even this initial boundary would eliminate the current flux of N onto the land and could trigger much more efficient and less polluting ways of enhancing food production. It would almost surely also trigger the return of N in human effluent back onto productive landscapes, thus further reducing the leakage of reactive N into ecosystems.

Phosphorus is a finite fossil mineral mined for human use and added naturally into the Earth System through geological weathering processes. The crossing of a critical threshold of P inflow to the oceans has been suggested as the key driver behind global-scale ocean anoxic events, potentially explaining past mass extinctions of marine life. Modelling suggests that a sustained increase of P inflow to the oceans exceeding 20% of the natural background weathering rate could have been enough to induce past formation of anoxic ocean bottoms. Of the global human extraction of ~20 Mt yr-1 of P, an estimated 10.5 Mt yr-1 is lost from the world's cropland and flows to the oceans.

It is difficult to precisely quantify a planetary boundary of P inflow to the oceans that places humanity at a safe distance from triggering widespread ocean anoxia. Presently anthropogenic P inflow to the ocean is suggested not to exceed a human-induced level of ~10 times the natural background rate of ~1 Mt P yr-1.

5.9 Boundary 5 – Rate of Biodiversity Loss

The current and projected rates of biodiversity loss constitute the sixth major extinction event in the history of life on Earth – the first to be driven specifically by the impacts of human activities on the planet. Previous extinction events, such as the Tertiary extinction of the dinosaurs and the rise of mammals, caused massive permanent changes in the biotic composition and functioning of Earth's ecosystems. This suggests non-linear and largely irreversible consequences of large-scale biodiversity loss.

Accelerated biodiversity loss during the Anthropocene is particularly serious, given growing evidence of the importance of biodiversity for sustaining ecosystem functioning and services and for preventing ecosystems from tipping into undesired states. A diversity of functional response mechanisms to environmental variation among species in an ecosystem maintains resilience to disturbances. Consequently, ecosystems (both managed and unmanaged) with low levels of diversity within functional groups are particularly vulnerable to disturbances and have a greater risk of undergoing catastrophic regime shifts.

Species play different roles in ecosystems. Species loss, therefore, affects both the functioning of ecosystems and their potential to respond and adapt to changes in physical and biotic conditions.

Currently, the global extinction rate far exceeds the rate of speciation, and consequently, loss of species is the primary driver of changes in global biodiversity. Since the advent of the Anthropocene, humans have increased the rate of species extinction by 100–1000 times the background rates that were typical over Earth's history. The average global extinction rate is projected to increase another 10-fold during the current century. Currently about 25% of species in well-studied taxonomic groups are threatened with extinction. Until recently, most extinctions (since 1500) occurred on oceanic islands. In the last 20 years, however, about half of the recorded extinctions have occurred on continents. The prime causes are

- land-use change (disappearance or disruption of biotopes)
- introduction of new, often invasive, species and
- climate change, more recently

Biodiversity is now broadly at risk throughout the planet. There is ample evidence that the current and projected extinction rates are unsustainable (Millennium Ecosystems Assessment 2005). Nonetheless, it remains very difficult to define a boundary level for the rate of biodiversity loss. A primary reason for including biological diversity as a planetary boundary is its role in providing ecological functions that support biophysical sub-systems of the Earth, and thus provide the underlying resilience of other planetary boundaries.

5.10 Boundary 6 – Global Freshwater Use

The global freshwater cycle has entered the Anthropocene because humans are now the dominant driving force altering global-scale river flow and the spatial patterns and seasonal timing of vapour flows. An estimated 25% of the world's river basins run dry before reaching the oceans due to use of freshwater resources in the basins.

Global manipulations of the freshwater cycle affect biodiversity, food, and health security and ecological functioning, such as provision of habitats for fish recruitment, carbon sequestration, and climate regulation, undermining the resilience of terrestrial and aquatic ecosystems. Threats to human livelihoods due to deterioration of global water resources are threefold:

- the loss of soil moisture resources (green water) due to land degradation and deforestation, threatening terrestrial biomass production and sequestration of carbon
- use and shifts in runoff (blue water) volumes and patterns threatening human water supply and aquatic water needs, and
- impacts on climate regulation due to decline in moisture feedback of vapour flows (green water flows) affecting local and regional precipitation patterns.

Estimates indicate that 90% of global green water flows are required to sustain critical ecosystem services, whereas 20%-50% of the mean annual blue water flows in river basins are required to sustain aquatic ecosystem functioning.

Green water flows influence, at the regional scale, rainfall levels through moisture feedback and, thereby, the availability of blue water resources. Green water-induced thresholds include collapse of biological sub-systems as a result of regional drying processes. Examples include the abrupt change from a wet to a dry stable state in the Sahel region approximately 5000-6000 years BP and the future risk of a rapid savannization of the Amazon rainforest due to abrupt decline in moisture feedback. Blue water-induced thresholds include collapse of riverine habitats if minimum environmental water flow thresholds are crossed and the collapse of regional lake systems, such as the Aral Sea.

The pressure on global freshwater resources is growing rapidly, mainly due to increasing food demands. Green water use in rain fed agriculture, currently estimated at ~5000 km^3 yr-1, may have to increase by 50% by 2030 to ~7500 km^3/yr, in order to ensure food security, whereas consumptive blue water use for irrigation may increase by 25%-50%, corresponding to 400-800 km^3 yr-1 by 2050 (Comprehensive Assessment of Water Management in Agriculture 2007). This indicates that the remaining safe operating space for water may be largely committed already to cover necessary human water demands in the future.

5.11 Boundary 7 – Land-System Change

Land-system change, driven primarily by agricultural expansion and intensification, contributes to global environmental change, with the risk of undermining human well-being and long-term sustainability. Conversion of forests and other ecosystems to agricultural land has occurred at an average rate of 0.8% yr^{-1} over the past 40-50 years and is the major global driver behind loss of ecosystem functioning and services. Humanity may be reaching a point where further agricultural land expansion at a global scale may seriously threaten biodiversity and undermine regulatory capacities of the Earth System by affecting the climate system and the hydrological cycle.

As a planetary boundary, the authors propose that no more than 15% of the global ice-free land surface should be converted to cropland. Because this boundary is a complex global aggregate, the spatial distribution and intensity of land-system change is critically important for the production of food, regulation of freshwater flows, and feedbacks to the functioning of the Earth System. This metric depends on the tight coupling with the other boundaries: P and N use, rate of biodiversity loss, and global freshwater use.

For humanity to stay within this boundary, cropland should be allocated to the most productive areas, and processes that lead to the loss of productive land, such as land degradation, loss of irrigation water, and competition with land uses such as urban development or biofuel production, should be controlled. Demand-side processes may also need to be managed; these include diet, per capita food consumption, population size, and wastage in the food distribution chain. Agricultural systems that better mimic natural processes, e.g., complex agro-ecosystems, could allow an extension of this boundary.

Land-system change may act as a slow variable that influences other boundaries, such as biodiversity, water, and climate, or they can trigger rapid changes at the continental scale when land-cover thresholds are crossed. If enough high-productivity land is lost to degradation, biofuel production, or urbanization, food production may spread into marginal lands with lower yields and a higher risk of degradation.

The land-system boundary should be implemented at multiple scales through a fine-grained global land architecture that

- reserves the most productive land for agricultural use
- maintains high conservation-value forests and other ecosystems in their current states, and
- maintains carbon-rich soils and ecosystems in their undisturbed or carefully managed condition.

About 12% of the global land surface is currently under crop cultivation. The allowed 3% expansion, approximately 400 Mha, to the level we propose as a land-system boundary will most likely be reached over the coming decades and includes suitable land that is not either currently cultivated or is under forest cover, e.g., abandoned cropland in Europe, North America, and the former Soviet Union and some areas of Africa's savannahs and South America's cerrado.

5.12 Boundary 8 – Aerosol Loading

Atmospheric aerosol loading is an anthropogenic global change process with a potential planetary boundary for two main reasons: (i) the influence of aerosols on the climate system and (ii) their adverse effects on human health at a regional and global scale.

Human activities since the pre-industrial era have doubled the global concentration of most aerosols. Aerosols influence the Earth's radiation balance directly by scattering incoming radiation back to space or indirectly by influencing cloud reflectivity and persistence. Aerosols can also influence the hydrological cycle by altering the mechanisms that form precipitation in clouds. Although the influences of aerosols on the Asian monsoon are widely accepted, there is still a great deal of uncertainty surrounding the physical processes underlying the effects and the interactions between them.

From the perspective of human-health effects, fine particulate air pollution (PM2.5) is responsible for about 800 000 premature deaths and an annual loss of 6.4 million life years, predominantly in developing Asian countries.

The same aerosol components, e.g., particulates, tropospheric ozone, oxides of sulphur and nitrogen lead to other deleterious effects. Crop damage from exposure to ozone, forest degradation and loss of freshwater fish due to acidic precipitation, changes in global precipitation patterns and in energy balance are further examples of indirect effects of air pollution on human well-being. It is not yet possible to identify a safe boundary value for aerosol loading.

5.13 Boundary 9 – Chemical Pollution

Primary types of chemical pollution include radioactive compounds, heavy metals, and a wide range of organic compounds of human origin. Chemical pollution adversely affects human and ecosystem health, which has most clearly been observed at local and regional scales but is now evident at the global scale. Our assessment on why chemical pollution qualifies as a planetary boundary rests on two ways in which it can influence Earth System functioning: (i) through a global, ubiquitous impact on the physiological development and demography of humans and other organisms with ultimate impacts on ecosystem functioning and structure and (ii) by acting as a slow variable that affects other planetary boundaries. For example, chemical pollution may influence the biodiversity boundary by reducing the abundance of species and potentially increasing organisms' vulnerability to other stresses such as climate change.

Chemical pollution also interacts with the climate-change boundary through the release and global spread of mercury from coal burning and from the fact that most industrial chemicals are currently produced from petroleum, releasing CO_2 when they are degraded or incinerated as waste.

Setting a planetary boundary for chemical pollution requires knowledge of the critical impacts on organisms. Deleterious consequences could be caused by direct exposure to chemicals in the abiotic environment – air, water, or soil – or through bioaccumulation or biomagnification up food chains.

By current estimates, there are 80 000 to 100 000 chemicals on the global market (U.S. EPA and EU Commission). It is impossible to measure all possible chemicals in the environment, which makes it very difficult to define a single planetary boundary derived from the aggregated effects of tens of thousands of chemicals. Some toxicity data exist for a few thousand of these chemicals, but there is virtually no knowledge of their combined effects. One may set a boundary for persistent pollutants with global distributions, or identify unacceptable, long-term, and large-scale effects on living organisms of chemical pollution.

5.14 Planetary boundaries and resource management

The approach to or crossing of planetary boundaries is in many ways the result of unsustainable management of natural resources. This is in particular obvious for the climate change boundary, as the main reason for increased global temperature is emission of greenhouse gases, to a very large extent carbon dioxide from the combustion of fossil fuels. The same holds true for ocean acidification as it is caused by carbon dioxide dissolving in the sea water and forming bicarbonate, and thus increasing the acidity of the water. The planetary boundaries research thus emphasises the urgency to reduce our dependency of fossil fuels or, in the case they are used, rely on Carbon Capture and Storage, CCS.

The other non-renewable resource which is in conflict with planetary boundaries is the use of mined phosphorous, mostly for agriculture but to an extent also for other chemicals, e.g. detergents. At present very little of the phosphorus from agricultural land is recovered from runoff from that land. But it is possible to do that. In particular it is possible to recover phosphorus from wastewater treatment plants, where almost all phosphorus from human food is collected. In industrialised countries the sludge from wastewater treatment is a main source of phosphorus and its return to agriculture would be an excellent example of resource recycling.

Also nitrogen flow has a number of serious impacts. These include not only eutrophication, which N shares with P, but also the fact that it is produced mainly with energy from fossil fuels. Again a larger share of recycling of the nitrogen as nitrate is needed in agriculture. Nitrogen is not a non-renewable resource but it is treated like one as its effects are similar.

Land should be seen as a natural resource to be properly managed. This may refer to the organic soil needed for cultivation, and which at present is lost on a planetary scale. Its formation is much slower than its destruction. Again proper agricultural practices are needed to reduce the loss of organic soil. Loss of soil is also adding to climate change as the prevailing mechanism is oxidation when access to air is increasing and then carbon dioxide is formed. The disappearance of ecological services on which society is very dependent is also connected to land use change.

Tightly coupled to land use is water use. Today fresh water resources, both surface water and ground water, is rapidly declining. The use of water has today most likely passed its planetary boundary, and a much more careful use of this critical resource is needed.

Chapter 5 sources:

Main source is the much edited text "Planetary Boundaries: Exploring the Safe Operating Space for Humanity" http://www.ecologyandsociety.org/vol14/iss2/art32/

See video with Johan Rockström introducing the planetary boundaries. https://www.youtube.com/watch?v=RgqtrlixYR4

The figures, illustrations and data sources from the 2015 update of the Planetary Boundaries, (Steffen et. al, Science 16 January 2015) can be downloaded at

http://www.stockholmresilience.org/21/research/research-programmes/planetary-boundaries/planetary-boundaries-data.html

Planetary Boundaries 2.0 – new and improved http://stockholmresilience.org/21/research/research-news/1-15-2015-planetary-boundaries-2.0---new-and-improved.html

Chapter 6
Measures of resource flows – the ecological footprint

6.1 Measuring resource flows by one-dimensional methods

Resource flows are measured for products and services, as well as different "consumers" of products and services such as persons, companies, municipalities, countries and the whole world. With similar methods also environmental impacts are measured for the same categories.

The measurements of the resource flow or environmental impact of a product or a service should ideally include flows and impacts made over the entire lifecycle of that product or service. This is a difficult and complicated task. We will come back to how to approach life cycle assessment, LCA, in chapter 7. Here we will only say that when such a measurement is made a number of flows and impacts are reported, such as human health, ecosystems health, biodiversity decrease, air pollution, water pollution, acid rain, etc. Each one can then be discussed or evaluated separately.

Is it possible to summarise these flows or impacts in a single measure, that is, to use a single dimension to summarise a complicated multidimensional effect? Such one-dimensional measures are called proxy methods. 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. Here the dimension in kWh or Joules.

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 (Environmental Priority Strategies) method then using the willingness-to-pay for avoiding the impacts to estimate the costs. Here the dimension is USD or Euros.

In the MIPS (Material Input Per Service unit) 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. MIPS is a Material Intensity (MI) 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. Here the dimension is kg. We will come back to the MIPS method in Chapter 8.

Surface area use is the proxy method used for ecological footprints. In this method a calculation is made of the area in nature used for a service or a product. This method is today the most widely used proxy method for estimating the total impact of a person, household, a city or a country. Here the dimension is so-called global hectares, gha.

The Ecological Footprint has emerged as one of the world's leading measures of human demand on nature. The rest of this chapter will give a detailed account of the calculations, use and results of the ecological footprint method.

6.2 The Ecological Footprint

Human activities consume resources and produce waste, and as our populations grow and global consumption increases, it is essential that we measure nature's capacity to meet these demands. The Ecological Footprint has emerged as one of the world's leading measures of human demand on nature. Simply put, Ecological Footprint Accounting addresses whether the planet is large enough to keep up the demands of humanity.

The concept of the ecological footprint was introduced by Mathis Wackernagel and William Rees at the University of British Columbia 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.

By measuring the Footprint of a population – an individual, city, business, nation, or all of humanity – we can assess our pressure on the planet, which helps us manage our ecological assets more wisely and take personal and collective action in support of a world where humanity lives within the Earth's bounds.

Figure 6.1. Land use categories comprising the Ecological Footprint (see Borucke et al., 2013 for additional information on the calculation methodology for each of these categories). (Source: Global Footprint Network)

<u>Our current global situation</u>

Since the 1970s, humanity has been in ecological overshoot with annual demand on resources exceeding what Earth can regenerate each year. It now takes the Earth one year and six months to regenerate what we use in a year.

We maintain this overshoot by liquidating the Earth's resources. Overshoot is a vastly underestimated threat to human well-being and the health of the planet, and one that is not adequately addressed.

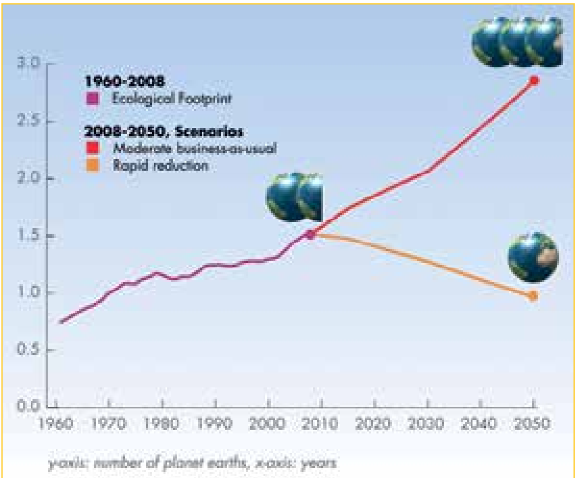

Figure 6.2. The World's Ecological Footprint. Today humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to regenerate what we use in a year. Moderate UN scenarios suggest that if current population and consumption trends continue, by the 2030s, we will need the equivalent of two Earths to support us.. (Source: Global Footprint Network)

The Ecological Footprint is now in wide use by scientists, businesses, governments, agencies, individuals, and institutions working to monitor ecological resource use and advance sustainable development.

The Ecological Footprint is an accounting tool that measures one aspect of sustainability: How much of the planet's regenerative capacity humans demand to produce the resources and ecological services for their daily lives and how much regenerative capacity they have available from existing ecological assets. It does so by means of two indicators:

- Ecological Footprint measures the biologically productive land and sea area – the ecological assets – that a population requires to produce the renewable resources and ecological services it uses.
- Biocapacity tracks the ecological assets available in countries, regions or at the global level and their capacity to produce renewable resources and ecological services, including our forests, pastures, cropland and fisheries. These areas, especially if left unharvested, can also absorb much of the waste we generate, especially our carbon emissions.

In economic terms, assets are often defined as something durable that is not directly consumed, but yields a flow of products and services that people do consume. Ecological assets are thus here defined as the biologically productive land and sea areas that generate the renewable resources and ecological services that humans demand. They include (Fig. 1):

1. cropland for the provision of plant-based food and fibre products;
2. grazing land and cropland for animal products;
3. fishing grounds (marine and inland) for fish products;
4. forests for timber and other forest products;
5. uptake land to sequester waste (CO_2, primarily from fossil fuel burning);
6. space for shelter and other urban infrastructure

6.3 Footprint of the world and footprints for nations

A country's Ecological Footprint of consumption is derived by tracking the ecological assets demanded to absorb its waste and to generate all the commodities it produces, imports and exports (Fig. 6.3). All commodities (or CO_2 waste) carry with them an embedded amount of bioproductive land and sea area necessary to produce (or sequester) them; international trade flows can thus be seen as flows of embedded Ecological Footprint.

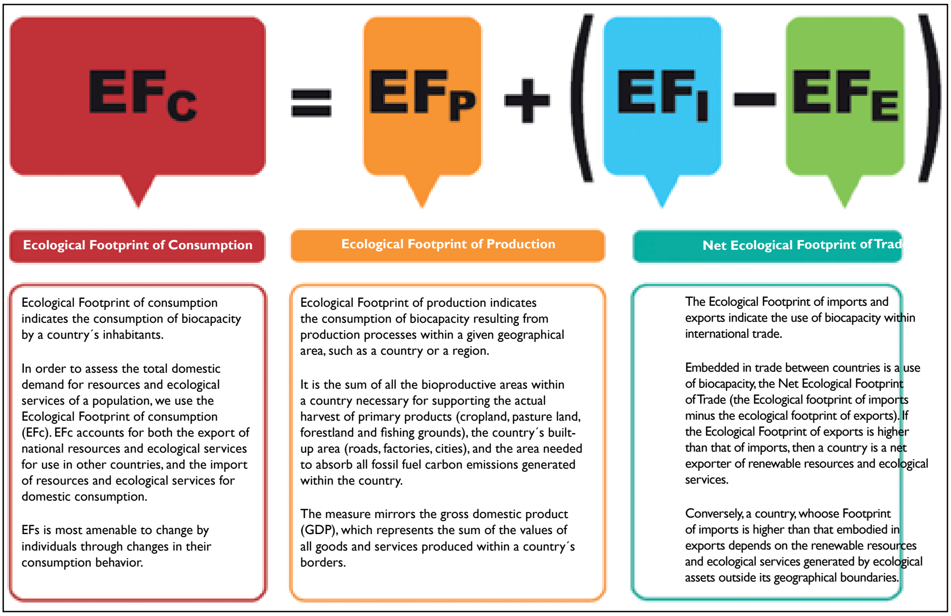

Figure 6.3. Tracking production, consumption and net trade with the Ecological Footprint: The Ecological Footprint associated with each country's total consumption is calculated by summing the Footprint of its imports and its production, and subtracting the Footprint of its exports. This means that the resource use and emissions associated with producing a car that is manufactured in China, but sold and used in Italy, will contribute to Italy's rather than China's Ecological Footprint of consumption. (Source: Global Footprint Network)

Both Ecological Footprint and biocapacity results are expressed in a globally comparable, standardized unit called a "global hectare" (gha) – a hectare of biologically productive land or sea area with world average bioproductivity in a given year.

While the Ecological Footprint quantifies human demand, biocapacity acts as an ecological benchmark and quantifies nature's ability to meet this demand. A population's Ecological Footprint can be compared with the biocapacity that is available – domestically or globally – to support that population, just as expenditure is compared with income in financial terms. If a population's demand for ecological assets exceeds the country's supply, that country is defined as running an ecological – or more precisely, a biocapacity – deficit. Conversely, when demand for ecological assets is less than the biocapacity available within a country's borders, the country is said to have an ecological – or biocapacity – reserve.

Today humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to regenerate what we use in a year. Moderate UN scenarios suggest that if current population and consumption trends continue, by the 2030s, we will need the equivalent of two Earths to support us. And of course, we only have one. Turning resources into waste faster than waste can be turned back into resources puts us in global ecological overshoot, depleting the very resources on which human life and biodiversity depend.

The result is collapsing fisheries, diminishing forest cover, depletion of fresh water systems, and the build-up of carbon dioxide emissions, which creates problems like global climate change. These are just a few of the most noticeable effects of overshoot.

Overshoot also contributes to resource conflicts and wars, mass migrations, famine, disease and other human tragedies—and tends to have a disproportionate impact on the poor, who cannot buy their way out of the problem by getting resources from somewhere else.

Global trends, however, hide the huge variability that exists at the regional level. Europe and Middle East/Central Asia experienced the largest increase in their per capita Ecological Footprint (+1.2 and +1.1 gha per person, respectively), but while Europe's population growth was relatively slow (+29%), population grew 330% in Middle East/Central Asia. North America had a smaller increase in per capita consumption (+ 0.6 gha per person) and a 63% growth in population. At the other end of the spectrum, Africa saw its per capita Ecological Footprint decline (-0.1 gha per person), while its population increased by 255%. In the Asia-Pacific region, per capita Ecological Footprint increased slightly (+0.6 gha per person), while population grew by 136% (Fig. 6.4).

The total Ecological Footprint of a country is a function of the average consumption pattern of each individual, the efficiency in production and resource transformation, and the number of individuals in the country. Biocapacity is determined by the available biologically productive land and sea areas and the capacity of these assets to produce resources and services useful for humans (this is determined by the prevailing technology and management practices implemented in these areas).

Biocapacity varies each year with ecosystem management, agricultural practices (such as fertilizer use and irrigation), ecosystem degradation, and weather, and population size. Footprint varies with consumption and production efficiency. Where a dotted line is shown, interpolation estimates have been used in place of highly unlikely outliers in the results.

In today's world, where humanity is already exceeding planetary limits, ecological assets are becoming more critical. Each country has its own ecological

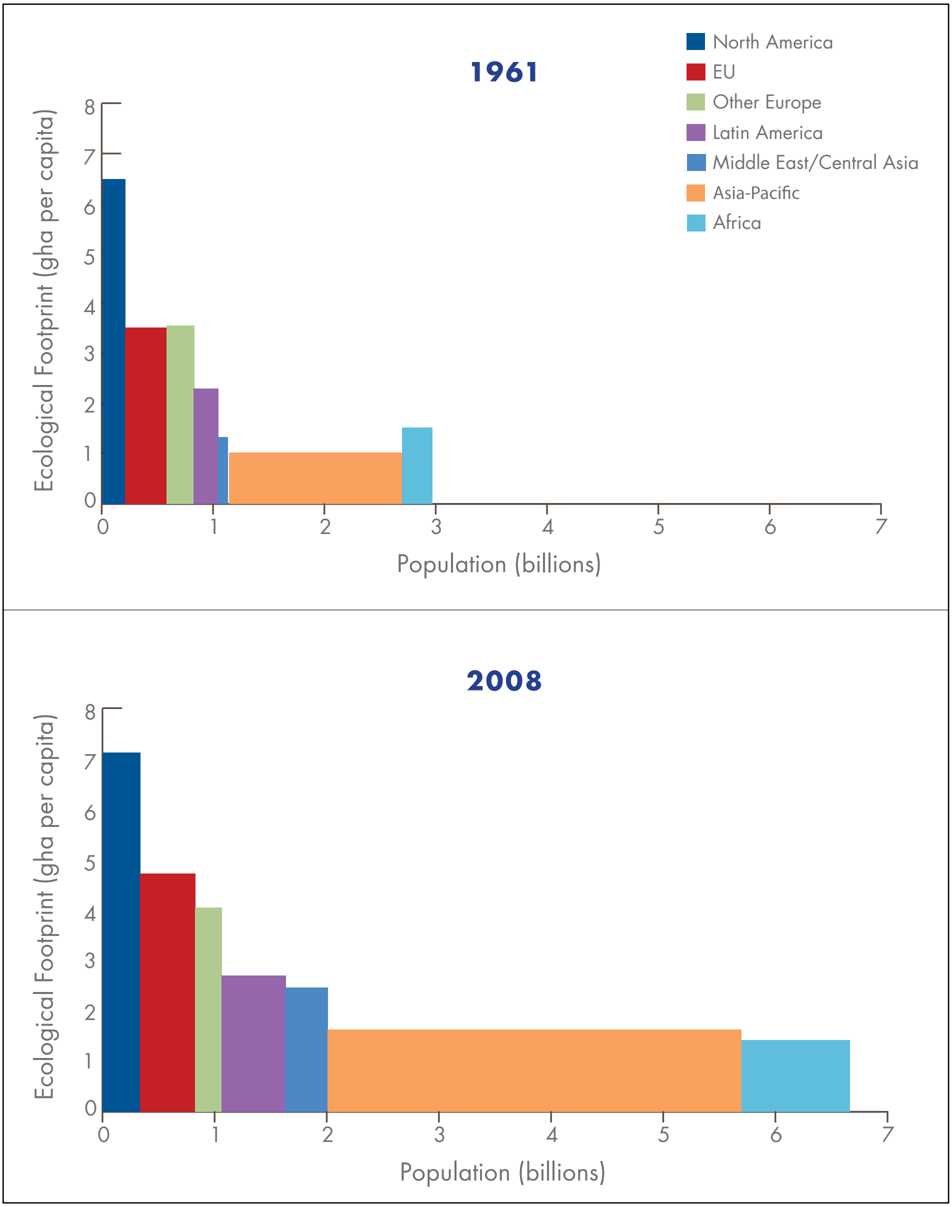

Figure 6.4: Ecological Footprint and population by world's regions in 1961 and 2008.The area within each bar represents the total Ecological Footprint for each region. (Source: Global Footprint Network)

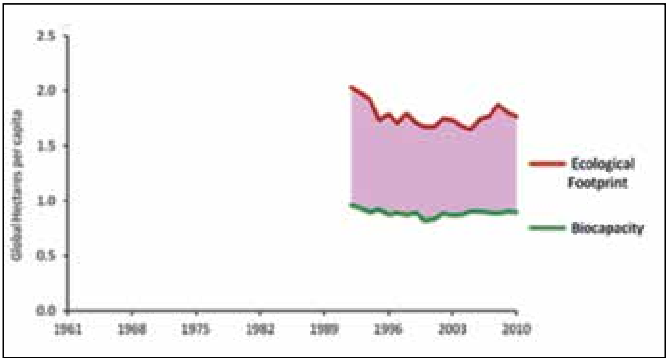

Figure 6.5 tracks the per-person resource demand Ecological Footprint and biocapacity in Uzbekistan since 1961. (Source: Global Footprint Network)

risk profile: Many are running ecological deficits, with Footprints larger than their own biological capacity. Others depend heavily on resources from elsewhere, which are under increasing pressure.

In some areas of the world, the implications of ecological deficits can be devastating, leading to resource loss, ecosystem collapse, debt, poverty, famine and war.

The Ecological Footprint is a resource accounting tool that helps countries understand their ecological balance sheet and gives them the data necessary to manage their resources and secure their future. National governments using the Footprint are able to:

1. Assess the value of their country's ecological assets
2. Monitor and manage their assets
3. Identify the risks associated with ecological deficits
4. Set policy that is informed by ecological reality and makes safeguarding resources a top priority
5. Measure progress toward their goals

It is almost certainly the case that countries and regions with surplus ecological reserves -not the ones relying on continued ecological deficit spending - will emerge as the robust and sustainable economies and societies of the future.

Today, more than 80% of the world's population lives in countries that use more resources than what is renewably available within their own borders. These countries rely for their needs on resource surpluses concentrated in ecological creditor countries, which use less biocapacity than they have. By comparison, in 1961, the vast majority of countries around the globe had ecological surpluses.

Those numbers have slowly dwindled; meanwhile, the pressure on the remaining biocapacity reserves continues to grow.

6.4 Global ecological overshoot

In less than 50 years, humanity doubled its demand for renewable resources and ecological services. At a global level, the causes are easily identified. Population growth recorded a 118% increase from 1961 to 2008, the period studied for this report, while the world's per capita Ecological Footprint increased by 15% (from 2.4 to 2.7 gha per person).

While ecological assets have long been ignored as irrelevant to a country's economy, the goods and services that sustain a healthy human society (access to food, safe water, sanitation, manufactured goods and economic opportunity) all depend on the functioning of healthy ecosystems.

According to Global Footprint Network's most recent National Footprint Accounts, in 2008 humanity consumed resources and ecological services 1.5 times faster than Earth could renew them – a 100% jump from 1961, when approximately 74% of the planet's biocapacity was consumed (Global Footprint Network, 2011). In other words, in 2008 human demand on the Earth's ecological assets was 50% greater than their capacity to keep up with this demand.

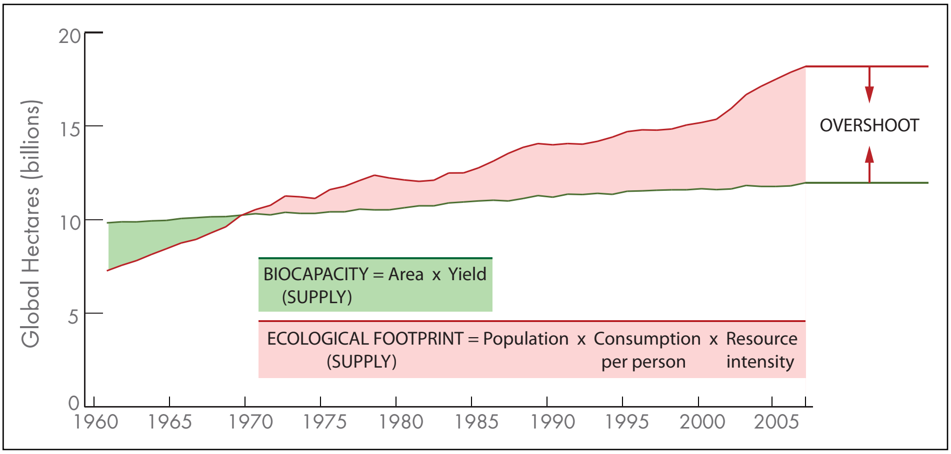

Figure 6.6: Trends in total Ecological Footprint and biocapacity between 1961 and 2008. The increase in biocapacity is due to an increase in land bioproductivity as well as in the areas used for human purposes. However, the increase in the Earth's productivity is not enough to compensate for the demands of a growing global population. (Source: Global Footprint Network)

This situation is known as "ecological overshoot" and its consequences can be seen in the form of climate change, water scarcity, land use change and land degradation, declining fisheries, loss of biodiversity, food crises and soaring energy costs. If human demand on nature continues to exceed what Earth can regenerate, then substantial changes in the resource base may occur, undermining economic performance and human welfare.

Humanity crossed the threshold in 1971, when the world went into global ecological overshoot. Recent studies (Moore et al., 2012) project that, if we continue on a "business-as-usual" path, it will take twice the ecological assets of the biosphere to meet our demands by the early 2030s. This level of overshoot is physically impossible in the long run. With growing resource scarcity and exceeded planetary boundaries, leaders need to be informed not only by value-added measures of economic activities, but also asset balances and how they impact our quality of life.

The Earth provides all that we need to live and thrive. So what will it take for humanity to live within the means of one planet?

Individuals and institutions worldwide must begin to recognize ecological limits. We must begin to make ecological limits central to our decision-making and use human ingenuity to find new ways to live, within the Earth's bounds.

This means investing in technology and infrastructure that will allow us to operate in a resource-constrained world. It means taking individual action, and creating the public demand for businesses and policy makers to participate. Using tools like the Ecological Footprint to manage our ecological assets is essential for humanity's survival and success. Knowing how much nature we have, how much we use, and who uses what is the first step, and will allow us to track our progress as we work toward our goal of sustainable, one-planet living.

6.5 Footprints for ecosystems, cities and business

While not a direct measure of species populations, the Ecological Footprint provides an indicator of the pressure on ecosystems and biodiversity by measuring the competing level of ecological demand that humans place upon the biosphere.

Global Ecological Footprint data show that humanity is using resources and producing CO2 emissions at a rate 44% greater than what nature can regenerate and reabsorb. This gap, known as ecological overshoot, results in the depletion of the natural capital that all species (including our own) depend on for their livelihood. It also results in the accumulation of carbon dioxide that leads to climate change, with profound implications for ecosystems and the species they support as well as for our societies well-being and economic stability.

Humanity's Ecological Footprint has grown 80% over the last four decades. The greater the gap between human demand and nature's regenerative capacity, the more pressure there will be on the resources other species need to survive, and the more perilously biodiversity will be under threat.

Local governments succeed by helping all their residents live fulfilling lives, both today and in the future. The availability of natural capital, nature's ability to renew and provide resources and services, is not the only ingredient in this vision. However, without natural capital – healthy food, energy for mobility and heat, fibre for paper, clothing and shelter, fresh air and clean water – such a vision is impossible. Thus, providing current and future human well-being depends on protecting natural capital from systematic overuse; otherwise, nature will no longer be able to secure society with these basic services.

Ecological Footprint accounts allow governments to track a city or region's demand on natural capital, and to compare this demand with the amount of natural capital actually available. The accounts also give governments the ability to answer more specific questions about the distribution of these demands within their economy. In other words, it gives them information about their resource metabolism.

For example, Footprint accounts reveal the ecological demand associated with residential consumption, the production of value-added products, and the generation of exports. They also help assess the ecological capacity embodied in the imports upon which a region depends. This can shed light on the region's constraints or future liabilities in comparison with other regions of the world, and identify opportunities to defend or improve the local quality of life. Footprint accounts help governments become more specific about sustainability in a number of ways. The accounts provide a common language and a clearly defined methodology that can be used to support staff training and to communicate about sustainability issues with other levels of government or with the public.

Footprint accounts add value to existing data sets on production, trade and environmental performance by providing a comprehensive way to interpret them. For instance, the accounts can help guide "environmental management systems" by offering a framework for gathering and organizing data, setting targets and tracking progress. The accounts can also serve as environmental reporting requirements, and inform strategic decision-making for regional economic development.

The global effort for sustainability will be won, or lost, in the world's cities, where urban design may influence over 70% of people's Ecological Footprint. High-Footprint cities can reduce this demand on nature greatly with existing technology. Many of these savings also cut costs and make cities more liveable.

Since urban infrastructure is long-lasting and influences resource needs for decades to come, infrastructure decisions make or break a city's future. Which cities are building future resource traps? Which ones are building opportunities for resource efficient and more competitive lifestyles?

Without regional resource accounting, governments can easily overlook or fail to realize the extent of these kinds of opportunities and threats. The Ecological Footprint, a comprehensive, science-based resource accounting system that compares people's use of nature with nature's ability to regenerate, helps eliminate this blind spot.

Businesses that look ahead and actively manage their ecological risks and opportunities can gain a strong competitive advantage.

The Ecological Footprint is being used to help corporations improve their market foresight, set strategic direction, manage performance and communicate their strengths.

By providing a common unit, the Footprint helps business to establish benchmarks, set quantitative targets and evaluate alternatives for future activities. The Footprint is compatible with all scales of company operations, and provides both aggregated and detailed results.

Ecological Footprint analysis reveals where regions, industrial sectors and companies will face increasing limits in resources such as energy, forest, croplands, pastures and fisheries. It also helps identify strategies that will succeed in a resource-constrained world, including products and services that will be most needed in the future.

6.6 Carbon Footprint

Today, the term "carbon footprint" is often used as shorthand for the amount of carbon (usually in tonnes) being emitted by an activity or organization, then referring to non-renewable sources of carbon, such as fossil fuels. The carbon component of the Ecological Footprint takes a slightly differing approach, translating the amount of carbon dioxide into the amount of productive land and sea area required to sequester carbon dioxide emissions. This tells us the demand on the planet that results from burning fossil fuels. Measuring it in this way offers a few key advantages.

On a practical level, the Ecological Footprint shows us how carbon emissions compare and interacts with other elements of human demand, such as our pressure on food sources, the quantity of living resources required to make the goods we consume, and the amount of land we take out of production when we pave it

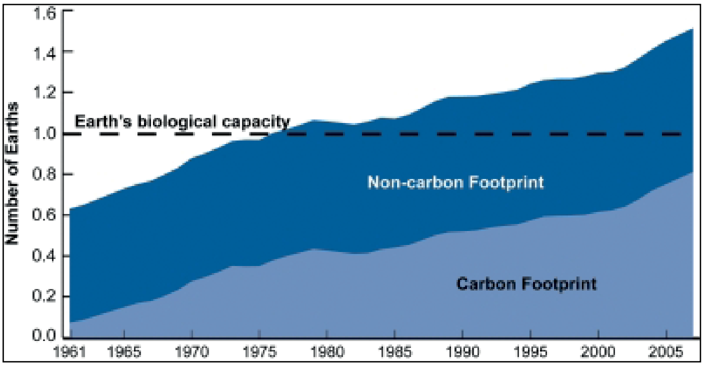

Figure 6.7. Earths biological capacity and carbon footprint (Source: Global Footprint Network)

over to build cities and roads. The carbon Footprint is 54% of humanity's overall Ecological Footprint and its most rapidly-growing component. Humanity's carbon footprint has increased 11-fold since 1961. Reducing humanity's carbon Footprint is the most essential step we can take to end overshoot and live within the means of our planet.

The Footprint framework enables us to address the problem in a comprehensive way, one that does not simply shift the burden from one natural system to another.

A carbon footprint is historically defined as "the total sets of greenhouse gas emissions caused by an organization, event, product or person. The total carbon footprint cannot be calculated because of the large amount of data required and the fact that carbon dioxide can be produced by natural occurrences. It is for this reason that Wright, Kemp, and Williams, writing in the journal Carbon Management, have suggested a more practicable definition:

"A measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_2e) using the relevant 100-year global warming potential (GWP100)."

Greenhouse gases (GHGs) can be emitted through transport, land clearance, and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings, and services. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide, or its equivalent of other GHGs, emitted.

Most of the carbon footprint emissions for the average U.S. household come from "indirect" sources, i.e. fuel burned to produce goods far away from the final consumer. These are distinguished from emissions which come from burning fuel directly in one's car or stove, commonly referred to as "direct" sources of the consumer's carbon footprint.

The average U.S. household carbon footprint is about 50 tons CO_2e per year. The single largest source of emissions for the typical household is from driving (gasoline use). Transportation as a whole (driving, flying & small amount from public transit) is the largest overall category, followed by housing (electricity, natural gas, waste, construction) then food (mostly from red meat, dairy and seafood products, but also includes emissions from all other food), then goods followed lastly by services. The carbon footprint of U.S. households is about 5 times greater than the global average, which is approximately 10 tons CO_2e per household per year. For most U.S. households, the single most important action to reduce their carbon footprint is driving less or switching to a more efficient vehicle.

In other words: When you drive a car, the engine burns fuel which creates a certain amount of CO_2, depending on its fuel consumption and the driving distance. (CO_2 is the chemical symbol for carbon dioxide). When you heat your house with oil, gas or coal, then you also generate CO_2. Even if you heat your house with electricity, the generation of the electrical power may also have emitted a certain amount of CO_2. When you buy food and goods, the production of the food and goods also emitted some quantities of CO_2.

Your carbon footprint is the sum of all emissions of CO_2 (carbon dioxide), which were induced by your activities in a given time frame. Usually a carbon footprint is calculated for the time period of a year.

The best way is to calculate the carbon dioxide emissions based on the fuel consumption. In the next step you can add the CO_2 emission to your carbon footprint. Below is a table for the most common used fuels:

Examples:

- For each liter of petrol fuel consumed 2.30 kg of carbon dioxide (CO_2) is emitted.
- If your car consumes 7.5 liter diesel per 100 km, then a drive of 300 km distance consumes 3 x 7.5 = 22.5 liter diesel, which adds 22.5 x 2.7 kg = 60.75 kg CO_2 to your personal carbon footprint.

Each of the following activities add 1 kg of CO_2 to your personal carbon footprint:

- Travel by public transportation (train or bus) a distance of 10 to 12 km
- Drive with your car a distance of 6 km or 3.75 miles (assuming 7.3 litres petrol per 100 km)
- Fly with a plane a distance of 2.2 km.
- Operate your computer for 32 hours (60 Watt consumption assumed)
- Production of 5 plastic bags

- Production of 2 plastic bottles
- Production of 1/3 of an American cheeseburger (yes, the production of each cheeseburger emits 3.1 kg of CO_2!)

The carbon footprint is a very powerful tool to understand the impact of personal behaviour on global warming. Most people are shocked when they see the amount of CO_2 their activities create! If you personally want to contribute to stop global warming, the calculation and constant monitoring of your personal carbon footprint is essential.

There are graphs available for the CO_2 emissions per capita by country (average carbon footprint by country). In the medium- and long term, the carbon footprint must be reduced to less than 2'000 kg CO_2 per year and per person. This is the maximum allowance for a sustainable living.

The following graph shows the total CO2 emission in million tons by country for the year 2002. Data source was the World Resources Institute (WRI). The CO_2 emissions for the year 2006 are about 12 to 15% higher than the figures shown here.

Below are the values of the carbon footprint by capita for the year 2002. Data source was again the World Resources Institute (WRI). Some remarks to these values:

- The world-wide average is 4 tons of carbon dioxide (CO_2) per person per year
- The average of all industrialised nations is about 11 tons of carbon dioxide (CO_2) per person per year
- In the medium and long term, a world-wide average emission of maximum 2 tons of carbon dioxide (CO_2) per person per year must be targeted. This amount is nowadays considered to be the maximum allowed quantity for a sustainable living on earth.
- The International Energy Institute (IEA) predicts a further increase of the world-wide CO_2 emissions by 55% within the next 25 years if no immediate actions to stop global warming are put in place. However, even in their alternative scenario where "... vigorous new policy measures already being contemplated.." are introduced, IEA predicts a growth of the CO_2 emissions by 28% compared to 2004!

6.7 Water Footprint

People use lots of water for drinking, cooking and washing, but even more for producing things such as food, paper, cotton clothes, etc. The water footprint is

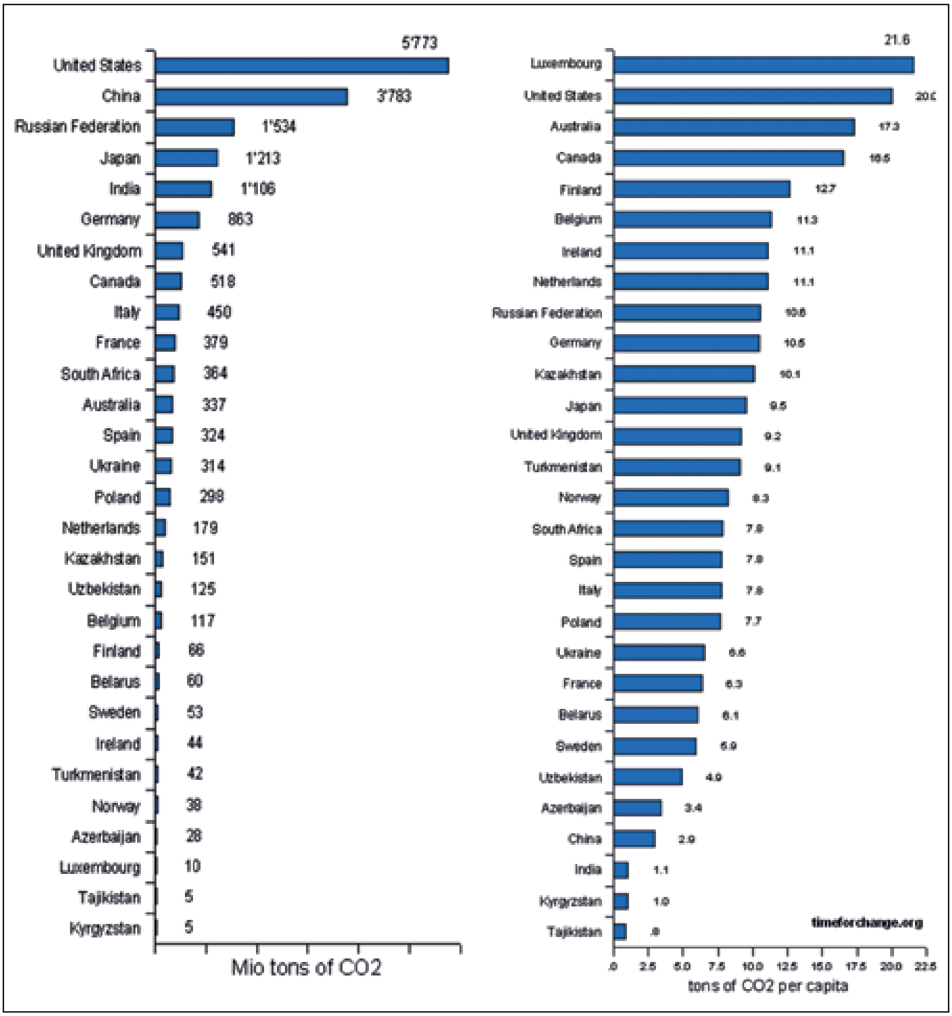

Figure 6.8. Country carbon footprint. Above left are the values of the carbon footprint by capita for the year 2002, and the right graph shows the total CO_2 emission in million tons by country for the year 2002. Data source was the World Resources Institute (WRI). The CO_2 emissions for the year 2006 are about 12 to 15% higher than the figures shown here. (Source: Global Footprint Network)

an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business.

Professor John Allan in 1993 introduced the "virtual water" concept, which measures how water is embedded in the production and trade of food and other products. For example, it a common thought that the water involved in a cup of coffee is just the water in the cup. There is actually 140 litres of ”virtual” water involved. The 140 litres of water is the amount of water that was used to grow, produce, package, and ship the coffee beans. A hamburger needs an estimated 2,400 litres of water. This hidden water is technically called virtual water. Therefore, eating a lot of meat means a large water footprint. The more food comes from irrigated land, the larger is the water footprint. But all kinds of products, not the least clothing, require more or less water in their production. Thus cotton products requires much more water and has a large water footprint.

Professor Arjen Y. Hoekstra, introduced the water footprint concept in 2002. The Water Footprint of a product is the volume of freshwater appropriated to produce the product, taking into account the volumes of water consumed and polluted in the different steps of the supply chain. One use to differentiate between blue, green and grey water footprints.

The blue water footprint is the volume of freshwater that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community (either lost through evapotranspiration, incorporated in products or transferred to non-blue catchments).

The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture) during production or those incorporated in products.

The grey water footprint is the volume of polluted water that associates with the production of all goods and services for the individual or community. The latter can be estimated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains at or above agreed water quality standards.

A.Y. Hoekstra says ”The interest in the water footprint is rooted in the recognition that human impacts on freshwater systems can ultimately be linked to human consumption, and that issues like water shortages and pollution can be better understood and addressed by considering production and supply chains as a whole.".. "Water problems are often closely tied to the structure of the global economy. Many countries have significantly externalised their water footprint, importing water-intensive goods from elsewhere. This puts pressure on the water resources in the exporting regions, where too often mechanisms for wise water governance and conservation are lacking. Not only governments, but also consumers, businesses and civil society communities can play a role in achieving a better management of water resources."

The Water Footprint Network, formed in 2002, developed The Global Water Footprint Standard – developed through a joint effort of, its partners, and scientists of the University of Twente in the Netherlands – has garnered international support from major companies, policymakers, NGOs and scientists as an important step toward solving the world's ever increasing water problems. The standard is contained in the Water Footprint Assessment Manual and can be downlaoaded from the Water Footprint Network website.

Water footprints vary enormously. Some examples:

The production of one kilogram of beef requires 15 thousand litres of water (93% green, 4% blue, 3% grey water footprint). There is a huge variation around this global average. The precise footprint of a piece of beef depends on factors such as the type of production system and the composition and origin of the feed of the cow.

The water footprint of a 150-gram soy burger produced in the Netherlands is about 160 litres. A beef burger from the same country costs about 1000 litres.

It also varies much between countries. The water footprint of Chinese consumption is about 1070 cubic meter per year per capita. About 10% of the Chinese water footprint falls outside China. Japan with a footprint of 1380 cubic meter per year per capita, has about 77% of its total water footprint outside the borders of the country. The water footprint of US citizens is 2840 cubic meter per year per capita. About 20% of this water footprint is external. The largest external water footprint of US consumption lies in the Yangtze river basin, China.

The global water footprint in the period 1996-2005 was 9087 Gm^3/yr (74% green, 11% blue, 15% grey). Agricultural production contributes 92% to this total footprint.

6.8 Calculating the ecological footprint

The detailed calculation methodology of the most updated Accounts – the National Footprint Accounts 2011 Edition – is described in Borucke et al. (2013). It reports the Ecological Footprint and biocapacity for about 150 countries and regions, from 1961 to 2008. A short description of the methodology and the data needs is also provided below.

The National Footprint Accounts 2011 Edition track human demand for resources and ecological services in terms of six major land use types (cropland, grazing land, forest land, carbon Footprint, fishing grounds, and built-up land). With the exception of built-up land and forest for carbon dioxide uptake, the Ecological Footprint of each major land use type is calculated by summing the contributions of a variety of specific products. Built-up land reflects the bioproductivity compromised by infrastructure and hydropower. Forest land for carbon dioxide uptake represents the carbon absorptive capacity of a world average hectare of forest needed to absorb anthropogenic CO_2 emissions, after having considered the ocean sequestration capacity (also called the carbon Footprint).

The Ecological Footprint calculates the combined demand for ecological resources and services wherever they are located and presents them as the global average area needed to support a specific human activity. This quantity is expressed in units of global hectares, defined as hectares of bioproductive area with world average bioproductivity. By expressing all results in a common unit, biocapacity and Footprints can be directly compared across land use types and countries.

Demand for resource production and waste assimilation are translated into global hectares by dividing the total amount of a resource consumed by the yield per hectare, or dividing the waste emitted by the absorptive capacity per hectare. Yields are calculated based on various international statistics, primarily those from the United Nations Food and Agriculture Organization (FAO Resource STAT Statistical Databases).

Yields are mutually exclusive: If two crops are grown at the same time on the same hectare, one portion of the hectare is assigned to one crop, and the remainder to the other. This avoids double counting. This follows the same logic as measuring the size of a farm: Each hectare is only counted once, even though it might provide multiple services.

The Ecological Footprint, in its most basic form, is calculated by the following equation:

$$EF = \frac{D_{ANNUAL}}{Y_{ANNUAL}}$$

where D is the annual demand of a product and Y is the annual yield of the same product (Monfreda et al., 2004; Galli et al., 2007). Yield is expressed in global hectares. In practice, global hectares are estimated with the help of two factors: The yield factors (that compare national average yield per hectare to world average yield in the same land category) and the equivalence factors (which capture the relative productivity among the various land and sea area types).

Therefore, the formula of the Ecological Footprint becomes:

$$EF = \frac{P}{Y_N} \cdot YF \cdot EQF$$

where P is the amount of a product harvested or waste emitted (equal to D above), YN is the national average yield for P, and YF and EQF are the yield factor and equivalence factor, respectively, for the country and land use type in question. The yield factor is the ratio of national- to world-average yields.

It is calculated as the annual availability of usable products and varies by country and year. Equivalence factors translate the area supplied or demanded of a specific land use type (e.g., world average cropland, grazing land, etc.) into units of world average biologically productive area (global hectares) and vary by land use type and year.

Annual demand for manufactured or derivative products (e.g., flour or wood pulp), is converted into primary product equivalents (e.g., wheat or roundwood) through the use of extraction rates. These quantities of primary product equivalents are then translated into an Ecological Footprint. The Ecological Footprint also embodies the energy required for the manufacturing process.

6.9 Consumption, production and trade

The National Footprint Accounts calculate the Footprint of a population from a number of perspectives. Most commonly reported is the Ecological Footprint of consumption of a population, typically just called the Ecological Footprint. The Ecological Footprint of consumption for a given country measures the biocapacity demanded by the final consumption of all the residents of the country. This includes their household consumption as well as their collective consumption, such as schools, roads, fire brigades, etc., which serve the household, but may not be directly paid for by the households.

In contrast, a country's primary production Ecological Footprint is the sum of the Footprints for all resources harvested and waste generated within the country's geographical borders. This includes all the area within a country necessary for supporting the actual harvest of primary products (cropland, grazing land, forest land, and fishing grounds), the country's infrastructure and hydropower (built-up land), and the area needed to absorb fossil fuel carbon dioxide emissions generated within the country (carbon Footprint).

The difference between the production and consumption Footprint is trade, shown by the following equation:

$$EF_C = EF_P + EF_I - EF_E$$

where EFc is the Ecological Footprint of consumption, EFp is the Ecological Footprint of production, and EFi and EFe are the Footprints of imported and exported commodity flows, respectively.

There are a number of simple calculation tools to estimate your own personal footprint. Some of them are

Global Footprint Network www.footprintnetwork.org/en/index.php/GFN/page/personal_footprint/

World Wildlife Found, WWF http://footprint.wwf.org.uk/

Earthday Network http://www.earthday.net/footprint/

6.10 Calculating biocapacity

A national biocapacity calculation starts with the total amount of bioproductive land – or ecological assets – available. "Bioproductive" refers to land and water that supports significant photosynthetic activity and accumulation of biomass, ignoring barren areas of low, dispersed productivity. This is not to say that areas such as the Sahara Desert, Antarctica, or Alpine mountaintops do not support life; their production is simply too widespread to be directly harvestable by humans.

Biocapacity is an aggregated measure of the amount of land available, weighted by the productivity of that land. It represents the ability of the biosphere to produce crops, livestock (pasture), timber products (forest), and fish, as well as to uptake carbon dioxide in forests. It also includes how much of this regenerative capacity is occupied by infrastructure (built-up land). In short, it measures the ability of available terrestrial and aquatic areas to provide ecological resources and services. A country's biocapacity for any land use type is calculated as:

$$BC = A \cdot YF \cdot EQF$$

where BC is the biocapacity, A is the area available for a given land use type, and YF and EQF are the yield factor and equivalence factor, respectively, for the country land use type in question.

Chapter 6 sources:

Section 6.1 Chapter 7. Ready-made Methods for Life Cycle Impact Assessment in Baltic University Programme Environmental Management, Book 3. Product Design and Life Cycle Assessment by Ireneusz Zbicinski, John Stavenuiter, Barbara Kozlowska, and Hennie van de Coevering.

http://www.balticuniv.uu.se/index.php/boll-online-library/828-em-3-product-design-and-life-cycle-assessment-

Global Footprint Network http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/

Wackernagel et al. 2006. The Ecological Footprint of cities and regions; comparing resource availability with resource demand. Environment and Urbanization 18(1): 103–112.

Carbon footprint Wikipedia http://en.wikipedia.org/wiki/Carbon_footprint

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Water use in Wikipedia http://en.wikipedia.org/wiki/Water_use

III
Quantitative Resource Theories and Services

Chapter 7
The life cycles of resources

7.1 The role of Life cycling thinking

Products (goods and services) contribute to various environmental impacts over their life-time. Life Cycle Thinking (LCT) is a concept that accounts for the up-stream and downstream benefits and trade-offs. LCT seeks to identify environmental improvement opportunities at all stages across its life cycle, from raw material extraction and conversion, through product manufacture, product distribution, use and fate at the end-of-life stage. Its fundamental aim is to provide a structured and comprehensive approach in support of the overall reduction of product impacts and to help optimize benefits.

In this context, LCT is essential to sustainable consumption and production as well as, to sustainable development. It is about going beyond the traditional focus on production site and manufacturing processes, in order to include the environmental, social, and economic impact of a product over its entire life cycle.

The precursors of Life Cycle Thinking emerged in the late 1960s and early 1970s from concerns about limited natural resources, particularly oil. They came in the form of global modelling studies and energy audits. They were referred to as Resource and Environmental Profile Analyses (REPA) and Net Energy Analyses. Since the 1970s, needs have changed and techniques have improved. Life Cycle Thinking has become a key complementary tool in policy and decision making, both in government and business.

Life Cycle Thinking is increasingly important in the development of key environmental policies around the world. In the European Union Life Cycle Thinking is at the heart of a growing number of policies and instruments in areas such as Integrated Product Policy, Sustainable Consumption and Production, Green Public Procurement, Environmental Management and Audit, Eco-labelling and Eco-design.

Life Cycle Thinking constitutes is also a key element in EU:s Waste Framework Directive and the Thematic Strategy on the prevention and recycling of waste. It is a key component of the Thematic Strategy on the sustainable use of natural resources.

Life Cycle Thinking is also a way to make us mindful of how everyday life has an impact on the environment, by evaluating the total impact of both consuming products and engaging in activities. When consuming a product, a series of associated activities are required to make it happen. Raw material extraction, material processing, transportation, distribution, consumption, reuse/recycling, and disposal must all be considered when evaluating the environmental impact of the life cycle of the product.

Life Cycle Thinking can be applied to the consumption of any socio-economic activity such as watching a movie, making arts and crafts, or cooking dinner. For example, renting a movie, which seems to be a harmless activity, would involve burning gasoline to drive to the video store, using electricity to power the television and DVD player, and consuming power from the remote's batteries.

When trying to analyse quantitatively the impacts of life cycles, an assessment approach is taken because the chain can become so complex that it is impossible to figure out in detail the life cycle of a specific process. Still Life Cycle Thinking overall is a way to become more mindful of the complexities of consuming products and engaging in activities and how they affect the environment.

The project The Story of Stuff is a video project to demonstrate and make us aware of the impact of life cycles of product we consume daily. It is worth watching some of their videos.

7.2 Principles and applications of life cycle thinking

The product life cycle (Fig. 7.1) is shown in five distinct phases, all of which interact with the environment. For most products, the life cycle stage of use is far longer than the other stages, and there may also be periods of storage and non-use between the stages shown. Usually, but not always, these stages will be environmentally benign. It is worth noticing that in the flow-sheet with the feedback loops, the potential for recycling, remanufacturing, reuse, and the strategies (Fig. 7.1), it becomes obvious that re-use is the strategy that potentially has the lowest environmental impact, merely based on the fact that this involves fewer stages. Each stage uses energy and has a certain environmental impact. Products may have totally different environmental impacts during different stages of their life cycle. Therefore, the whole of the life-cycle of a product needs to be taken into consideration. For example, some materials may have an adverse environmental consequence when extracted or processed, but be relatively benign in use and easy to recycle. An example is the case for aluminium. On the other hand, a washing machine will create the bulk of its environmental impact during its use

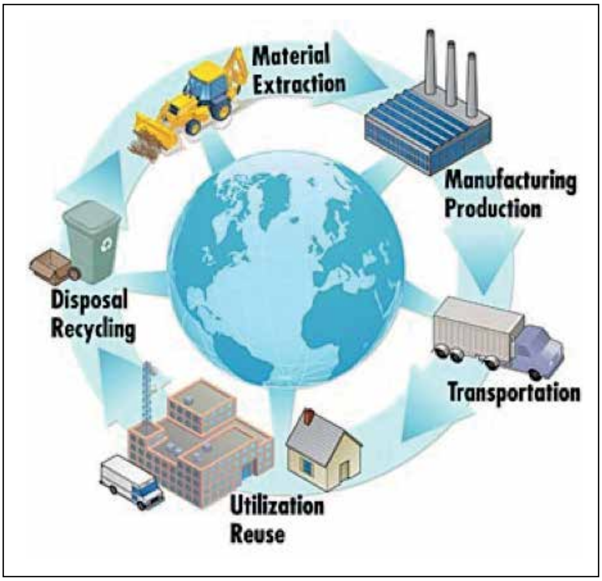

Figure 7.1 Life cycle elements.

phase, mainly due to water and energy consumption which in turn generate water and air pollution, as well as solid waste.

LCT is essential to sustainable consumption and production. It is about going beyond the traditional focus on production sites and manufacturing processes, and expanding it to take into consideration the environmental, social, and economic impact of a product over its entire life cycle, including the consumption and end of use phase. To this extend, the key principles of Extended Producer Responsibility (EPR) and Integrated Product Policy (IPP) are highly promoted.

Extended Producer Responsibility EPR means that the producers take responsibility for their products from cradle to grave and therefore, they should develop products that have improved performance throughout all stages of the product life cycle as is mentioned in the previous paragraph. At each stage of the life cycle, opportunities for improved performance exist. The producers are required to take back products when they are wasted. This is now implemented from small electronic gears to cars. Of course it is in the interest of the producer that the wasted product may be dismantled and the individual components can be taken care of. This has led to a reduction of complicated assemblies consisting of papers or wood, plastics and metals which cannot be separated. Remember also the producer has to bear the costs for material which cannot be recycled.

The goal of Integrated Product Policy, IPP, is to reduce a product's resource use and its emissions to the environment as well as improve its socio-economic performance throughout its life cycle. This may facilitate links between the economic, social and environmental dimensions within an organisation and throughout its entire value chain. The European Commission says

"The life-cycle of a product is often long and complicated. It covers all the areas from the extraction of natural resources, through their design, manufacture, assembly, marketing, distribution, sale and use to their eventual disposal as waste. At the same time it also involves many different actors such as designers, industry, marketing people, retailers and consumers. All products cause environmental degradation in some way, whether from their manufacturing, use or disposal. Integrated Product Policy (IPP) seeks to minimize these by looking at all phases of a products' life-cycle and taking action where it is most effective.

With so many different products and actors there cannot be one simple policy measure for everything. Instead there is a whole variety of tools - both voluntary and mandatory - that can be used to achieve this objective. These include measures such as economic instruments, substance bans, voluntary agreements, environmental labelling and product design guidelines."

Life Cycle Thinking promotes awareness that strategic selections are not isolated but influence a larger system. For example, one may consider buying office paper. In order to create 50,000 sheets of office paper, it takes 24 trees and 2.3 m^3 of landfill space for their final disposal. In this manner, paper made from recycled material needs to be promoted in order to avoid cutting more trees and using more landfill, which in turn leads to achieving sustainability.

Life Cycle Thinking make choices for the longer term, considering all environmental and social issues associated with those choices. LCT helps decision makers to avoid short term decisions that lead to environmental degradation. As an example, over-fishing might provide short-term benefits to people in the fishing business, but would ultimately result to unexpected long-term effects and great losses.

Life Cycle Thinking improve entire systems, not single parts of systems, by avoiding decisions that fix one environmental problem but cause another unexpected or costly environmental problem. LCT helps to avoid shifting problems from one life cycle stage to another, from one geographic region to another and from one environmental medium (air, water or soil) to another. Instead it promotes informed selections - not necessarily "right" or "wrong" ones. LCT simply helps decision makers to put decisions in context with facts from all parts of the system or life cycle.

LCT also applies to the daily decisions made at home and/or workplace; decisions about creating sustainable services and how to develop modern communities. All stakeholders of the community (citizens, businesses, and governments) are finding ways to promote LCT, as well as balance the impacts of their choices. LCT concept can be incorporated into our everyday life. For instance, thinking about how industries and homes currently use water and what they release into water systems, are key life cycle considerations. With life cycle information, industrial processes can be redesigned in a way to preserve water quality and improve access to clean water for local people.

7.3 Life cycle costs

Life-cycle cost analysis (LCCA) is a tool to determine the total costs to purchase, own, operate, maintain and, finally, dispose of an object or process. It is used to select the most cost-effective option among different competing alternatives when each is equally appropriate to be implemented on technical grounds. For example, for a highway pavement, in addition to the initial construction cost, LCCA takes into account all the user costs, (e.g., reduced capacity at work zones), and agency costs related to future activities, including future periodic maintenance and rehabilitation. All the costs are usually discounted and total to a present day value known as net present value (NPV).

In the past LCC has been primarily a way of assessing "cost of ownership" throughout the life cycle of a product, which includes capital cost, operating costs, servicing and maintenance, and eventually disposal. The concept can however be extended to cover the product's impact on the environment and the energy needed. It is important to take into consideration the fact that all purchased materials have required energy at all their life cycle stages, from the extraction of raw materials to manufacture.

Ideally the product life cycle approach should take into account the interrelationship of all life cycle stages, from raw materials extraction to the product manufacture, its use phase and finally the disposal, which however can include recycling for the creation of new raw materials. In both cases, without consideration of the full life cycle of goods and services (supply/use/end-of-life), the environment suffers – resulting in poorer financial performance and higher potential for reputation damage. It is obvious that, a life cycle approach to community planning and development can lead to fewer environmental impacts from materials used, construction practices, and waste management, as well as the energy and water used by people living and working in the community.

Thus in order to perform a LCCA scoping is critical - what aspects are to be included and what not? If the scope becomes too large the tool may become impractical to use and of limited ability to help in decision-making and consideration of alternatives; if the scope is too small then the results may be skewed by the choice of factors considered such that the output becomes unreliable or partisan. Usually the LCCA implies that energy and environmental costs are included.

There are international standards to deal with Life Cycle Assessment but not the same for Life Cycle Costs. The ISO 15686 standard, however, is used to evaluate buildings and other contractions then referring to the lifetime of in service, when they can be used, so called service life planning. It is a decision process which addresses the development of the service life of a building component, building or other constructed work like a bridge or tunnel. This in turn is used to secure a life-cycle cost profile (or Whole-life cost when called for) whilst addressing environmental factors like life cycle assessment and service life care and end of life considerations including obsolescence and embodied energy recovery. Service life planning is increasingly being linked with sustainable development and whole life value.

7.4 Life cycle assessment

Life cycle assessment (LCA), is a rather new tool in environmental management, which has the capacity – at least in principle – to answer this seemingly easy question: Is a product environmentally friendly? 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.

As an example of the LCA approach: In a survey on green milk packaging a majority would certainly find a returnable milk bottle much preferable to a disposable milk carton. 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. The most advisable solution would combine the environmental advantages of the two considered alternatives.

A widely known definition of LCA was proposed by SETAC (Society of Environmental Toxicology and Chemistry), which was a pioneer in publishing its “Code of Practice”. It 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."

All LCA methods have in common a holistic viewpoint on the life cycle and dealing with environmental aspects of all emissions and material consumption resulting from the life cycle. Even if there is no internationally accepted methodology of LCA an international standard exists based on the ISO 14040 series.

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.

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

- Infrastructure
- Processindustry
- Energyproduction
- Transportation
- Heavyindustry
- Consumergoods
- Livelihood

7.5 Applications of LCA

Today's LCA approaches are valid only for incremental changes in the product of interest and defined geopolitical regions. LCA integrates over time and space. A desegregation of these two parameters are needed to get a more precise result. Environmental impact is depending on location. For example acidification is very different in different places. 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.

Qualitative LCA methods analyse the life cycle of a product in environmental terms directly on the basis of emissions released and the consumption of raw materials. There are several methods for assessing the impacts along the life cycle. A much used methods 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. 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. 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.

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. Important methods include Eco-points, Eco-indicator, EPS system and the 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:

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. 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.

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.

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 7.3) 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, ne-

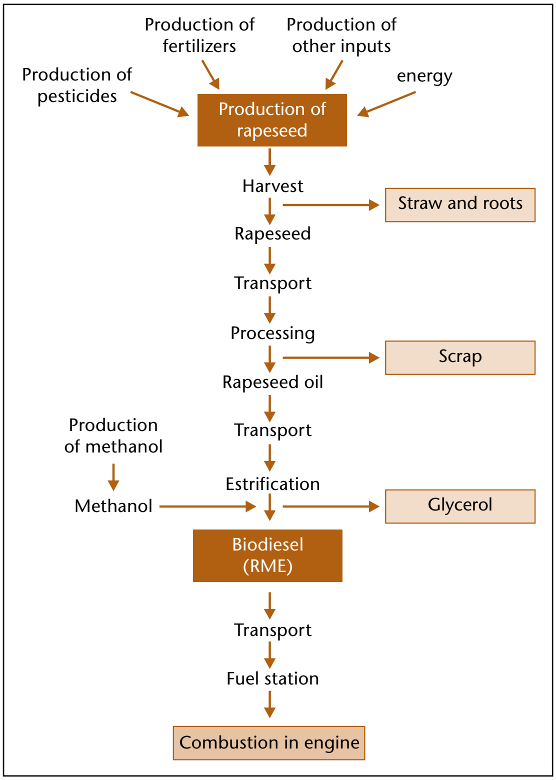

Figure 7.2 Process tree of the production and use of biodiesel.

glecting 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 low-

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

er 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.

7.6 Life Cycle Inventory (LCI) and impact assessment

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. 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.

The data should be quantitative and are used to build an inventory table. 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).

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. 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.

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:

- Compulsory steps: classification and characterisation.
- Optional steps: normalisation and weighting.

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).

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. 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.

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.

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.

7.7 Calculating an environmental profile of a life cycle

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. The two graphs in Figure 7.3 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.

The results from the characterisation step cannot be compared since they are usually presented in different units (CO_2eq, SO_2eq, CFC_{-11}eq, 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:

Normalized effect score = annual contribution to that effect in a certain area effect score for a given category. From the normalised environmental profile one can conclude, for instance, that product X constitutes 1% of all CO_2eq 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.

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

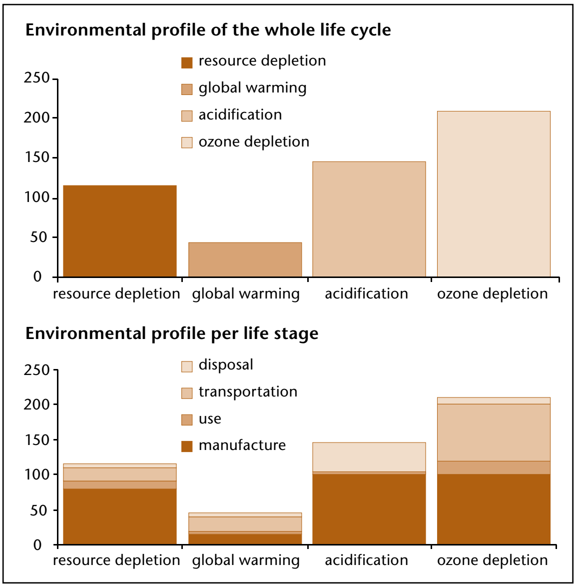

Figure 7.3 Environmental profiles. The impact of a life cycle may be expressed as the sum of each kind of impact summed over the entire life cycle (above), or as the impact expressed separately for each life stage (below). In this life cycle four impacts are considered (resource depletion; global warming; acidification; and stratospheric ozone depletion), and four life stages (disposal (wasting); transportation; use; and manufacture).

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 7.3 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.

7.8 The six RE- philosophy

Life cycle thinking plays a key role in the concept of pollution prevention in including the whole product life cycle and sustainability. Source reduction in a product life cycle perspective is then equivalent to eco-design principles and the "6 RE philosophy":

- Re-think the product and its functions. For example, the product may be used more efficiently, thereby reducing energy use and other natural resources.
- Re-duce energy and material consumption through-out a product's life cycle.
- Re-place harmful substances with more environmentally friendly alternatives.
- Re-cycle. Select materials that can be recycled, and build the product so that it is disassembled easier for recycling.
- Re-use. Design the product so parts can be reused.
- Re-pair. Make the product easy to repair so that the product does not yet need to be replaced.

In each life cycle stage there is the potential to lower resource consumption and improve the performance of products. The objective of this work is to identify improvements and to lower the impacts of goods or services (products) at all stage of associated life cycles, from raw material extraction and conversion, product manufacture, through distribution, use and eventual fate at the end-of-life. This is achieved using as a case study the life cycle analysis of a washing machine. The study also aims to take into consideration the environmental impacts of the processes within our direct control, the raw materials used, supply chains, product use, the effects of disposal and the possibilities for re-use and recycling.

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Chapter 8
Ecological rucksacks, MIPS and resource intensities

8.1 Resource-intensive material flows

Industrialized society is an enormous mobilizer of materials. We shall here discuss the size and the overall characteristics of these anthropogenic flows. We shall introduce the MIPS concept which has been developed to catch and describe the overall mobilization. Overall material flows will be described both for global human society and for some countries where specific studies have been done: Germany, the United States and Sweden.

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. 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.

8.2 The size of materials flows

Materials intensity is a measure of the amount of materials used to provide a certain amount of service. How are large flows of materials in one form or another either extracted from nature and fed into society to provide a certain service or, in an environmentally potentially significant way, mobilized in any way in nature to provide this service? The Wuppertal Institute for Climate, Environment and Energy in Germany has developed the MIPS concept (Materials Intensity Per Service unit) in order to answer this question.

MIPS works with the following five main input categories of materials flows: water, air, abiotic raw materials, biotic raw materials and soil movements (in agriculture and forestry). All the materials flows are measured by their weight. Different qualities like emissions, exhaustion of resources and the extent of the manipulation of nature are connected to these materials flows leading to, for example, various environmental damage and effects on health.

There are of course tremendous differences in the specific effects, effects per kilogram of material, caused by different materials flows or emissions, even if various sectors in society always use different combinations of materials, and therefore the effects might vary considerably. Thus, it is still of interest to show all the flows in terms of a common unit of measurement and weight is probably the most convenient one. What do the overall materials flows in industrialized society look like? Which flows dominate and what are the characteristic features of societal metabolism?

A materials flow account of the German economy showing the input and output of materials is presented in Table 8.1. The input is estimated according to the MIPS concept. Extracted useful materials are, after various degrees of transformations in the production system, used to serve different parts of the economy. Materials will end up in various output streams, possibly after a limited time of accumulation and recycling in the technosphere, in handled waste or in various emissions or losses to parts of the ecosphere. They may also be left behind when no longer in use as, for example, cables left in ground when obsolete. We shall start with the five MIPS categories when describing the total input and overall mobilization of materials.

Water is the totally dominating mobilized material in the German economy (Table 8.1): 69 billion tonnes per year corresponding to a daily water flow per person of 2.4 tonnes or cubic meters. The water flows accounted for here are generally the flows which are deviations from the natural flows or withdrawals from natural storage. The flow figure still does not include water corresponding to the natural evapotranspiration from growing plants cultivated and harvested in agriculture and forestry. These flows are even larger than those accounted for. It is estimated that each kilogram of dry biomass grown requires 150 to 800 kilograms of water in evapotranspiration.

Table 8.1 German material flows (Source: Wuppertal Institute, Bringezu et al 1996)

Table 3.1 Domestic overall account of the materials mobilization of Germany 1991 [Bringezu et al., 1995].

INPUT			**OUTPUT**		
	Total Mtonnes	*kg per capita & day*		*Total Mtonnes*	*kg per capita & day*
Water	**69 290**	**2 373**	**Water**	**69 290**	**2 373**
– Used	46 874	1 605	– Treated	13 857	475
– Unused	22 416	768	– Untreated	32 573	1 116
– Imports	0.2	0.00005	– Water losses and evaporation	5 395	185
			– Water diversion	17 459	598
			– Water exports	8	0.3
			Emissions to water	**34**	**1.2**
			– Dredging excavations	34	1.2
			– N and P from sewage	0.4	0.0001
Air	**781**	**27**	**Emissions to air**	**2 919**	**100**
– O_2 for combustion	725	25	– Water	1 850	63
– Production of O_2 and N_2	38	1.3	– CO_2	1032	35
– O_2 for steel production	18	0.6	– NO_x, SO_2, CO	20	0.7
			– Others	17	0.6
Abiotic raw materials	**3993**	**137**	**Waste disposal**		
– Used • minerals	829	28	**(excluding incineration)**	**2 891**	**99**
• ores	0.4	0.0001	– Controlled waste deposition	222	8
• energy carriers	366	13	– Landfill and mine dumping	2 669	91
– Unused • non-saleable prod.	2532	87			
• excavation	266	9			
Biotic raw materials	**82**	**2.8**			
– Plant biomass from cultivation	82	2.8			
– Fishing/hunting	0.4	0.0001			
Soil			**Soil**	**166**	**5.7**
– Erosion	**129**	**4.4**	– Erosion	129	4.4
			– Dissipative use of products		
			• fertilizers	35	1.2
			• sewage sludge	0.8	0.0002
			• compost	0.8	0.0002
			• pesticides	0.03	0.0001
Import	**433**	**15**	**Exports**	**211**	**7.2**
			Waste for utilization (stored)	64	2.2
			Accumulation (balance)	1 047	36
TOTAL			**TOTAL**		
– With water	**74 708**	**2558**	– With water	**74 350**	**2546**
– Without water	**5 418**	**186**	– Without water	**5 060**	**173**

The minor amount of the mobilized water is consumption or losses of fresh water, defined as fresh water that has been evaporated, transpired or incorporated into products, plant or animal tissue and is therefore unavailable for immediate reuse. The major amount is water flows that to various extents are deflections in space and time of natural flows or storage. However, the environmental importance may still be large because of the ecological significance of water availability and humidity levels. About one-third is unused water that is withdrawn for drainage only, for example, in mining and in rainwater drainage.

Air flows included in the MIPS are the flows in which air is used as a raw material. Air is mainly consumed in the combustion of fuels and is thus very strongly connected to the flow of fuels. The minor amount is used in industrial processes such as iron production. Each kilogram of unoxidized carbon in a fuel needs 2.7 kilograms of oxygen when burnt and producing carbon dioxide. The corresponding figure for the fuel hydrogen is 8 kilograms of oxygen when it is burnt to water. This means that 1 kg of oil or gasoline uses 3.4 kg of oxygen or 11 m3 of air for combustion.

However, the amount of air used is negligible compared to the total amounts available. Approximately one per cent of the oxygen in air corresponds to the estimated available total resources of fossil fuels and the living and dead organic materials in the ecosphere. Thus, air is inexhaustible and not a resources problem, but possible problems are related to air pollution. The pumping of air in industrial processes such as combustion and filtering, and in heating, cooling and ventilating buildings also requires resources (for example, electricity).

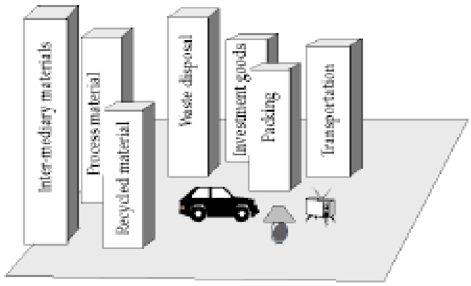
8.3 The ecological rucksack

The abiotic raw materials are extracted both from the lithosphere and from the soil in the ecosphere. Connected to the extraction of useful materials is an ecological 'rucksack' [Schmidt-Bleek 1994], namely, the flows of materials that are not included at all in products but are 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 which hold only small amounts of metals. The non-metal remainder is discarded in the refining process and is part of the rucksack.

The German annual domestic extraction of abiotic materials is about 4,000 Mtonnes or 50 tonnes per capita. Of this, about one-third is non-saleable materials like overburden. The market for metals and fossil fuels is to a large extent global. Densely populated industrialized countries are naturally often net importers of abiotic materials. The German rucksack connected to imports is nearly as large as the domestic one.

In industrialized countries the flow of renewable organic materials in the form of harvested biomass is inferior to that of exhaustible fossil organic materials (in the form of fossil fuels). In Germany the domestic energy carriers are more than 4 times larger than the biomass harvest, which amounts to 82 Mtonnes/year, or almost one tonne per capita. Total domestic abiotic materials extractions are about 50 times larger than the biotic ones. Inclusion of the net imports will raise this figure further.

The ecological rucksack



The MIPS measure gives the weight of material extracted from nature to obtain a certain service. Of the extracted material there is a useful part, which provides the service, and a non-useful part, called the rucksack. The return flow to nature, and its environmental impact, is not included in MIPS.

As an example, the MIPS measure of transporting oneself a distance with a car etc. is shown to the left. The rucksack, due to the extraction of various metals, etc. from nature, is normally much larger, sometimes several hundred-fold larger, than the material in the consumer goods itself.

Figure 8.1 The ecological rucksack (Source: Karlsson 1996)

In Germany the estimated amount of erosion associated with the input of biotic raw materials from cultivation exceeds even the dry weight of these raw materials. The erosion to biotic raw materials ratio has also increased during the 1980s.

The working of soils in agriculture (for example by ploughing) is not included in the figure for soil movements in Table 3.1. However, this mobilization is very large. If, say, half of the agricultural land of about 0.3 ha per person in Europe is ploughed every year to a depth of 0.2 metres, this annual movement of soil is about 600 m^3 or 1200 tonnes per capita which is very large compared to other flows except water.

8.4 Global anthropogenic flows

Major world-wide societal extractions from the lithosphere together with their rucksacks are summarized in Figure. 3.2. The extraction of lithospheric materials amounts to around 20,000 and 60,000 Mtonnes/year without and with the rucksack, respectively, corresponding to 4 and 12 tonnes per capita respectively. Mineral raw materials can be divided into four broad categories of use:

- energy minerals which are the fossil fuels, including peat;
- ore minerals used for the extraction of metals;
- minerals used for their chemical properties as raw materials for chemical compounds and fertilizers;
- minerals used for their special or aggregate physical properties.

This diverse group ranges from building materials such as sand, gravel and cement to special industrial minerals for abrasives.

Box 8.1 Global material turnover

Global material turnover is dominated by a few categories. At the top of the diagram we find black coal, lignite and oil and, in even larger amounts, their ecological rucksacks. All these turnovers represent the extraction of fossil fuels; all of them contribute to large-scale manipulation of the natural carbon cycle. The flows of the bulk materials, sand and gravel, are even larger but have small rucksacks and certainly not the same environmental impact.

High up in the diagram are also found phosphate, calcium carbonate, used in cement, and sulphur. All of these, together with nitrogen, belong to the category of macronutrients, as they are in comparatively large amounts needed for plant growth. The large-scale impact on the flows of these substances also has very destructive consequences, such as eutrophication and acidification.

Finally there are the metals. Only a few of them are in the upper part of the diagram: iron, aluminium (from bauxite) and copper. Further down is a series of metals used for special purposes. The weight of the rucksacks of these is often very large. For copper it is about 800 times larger than the metal itself and the mining of copper is both destructive and expensive.

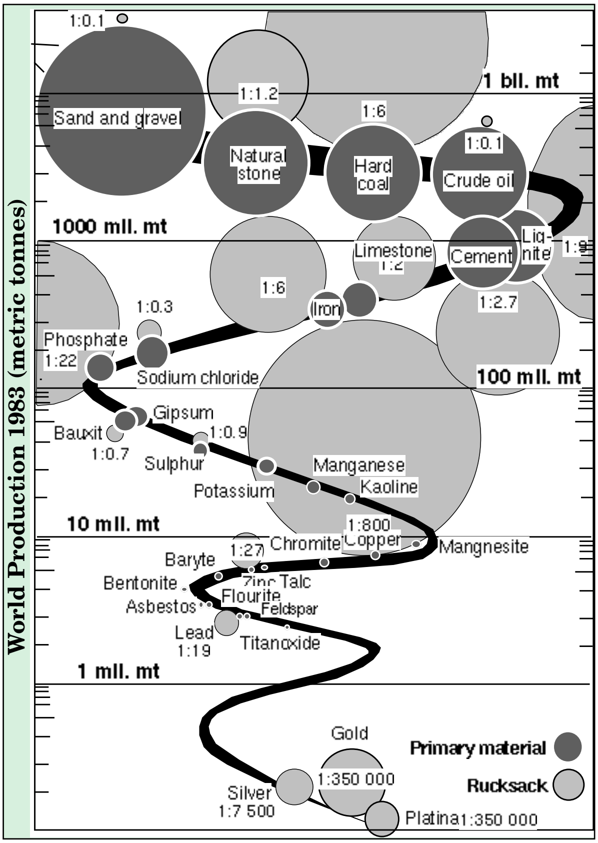


Figure 8. 2 Global material turnover, as described in the accompanying logarithmic diagram from the Wuppertal Institute.

Of the world-wide rucksack amounting to around 40,000 Mtonnes/year, about one-half is due to energy conversion; in practice the use of fossil hard and brown coal. These fuels are mostly extracted by open-cast mining, giving rise to large volumes of overburden. Some metals also contribute to the rucksack: for example, iron, because of its high use volume in society and copper, because of its low grade in ores and some high-volume non-metallic minerals such as minerals for phosphorus and concrete production. These rucksacks consist mainly of large dumps and translocated materials at the mine or refinery. Locally these may give rise to serious environmental effects.

World-wide, the extraction of mineral raw materials is dominated by building materials and energy minerals (fossil fuels), which are consumed roughly on the same scale, around 13,000 and 9,000 Mtonnes/year respectively. Building materials consist mainly of trivial materials like sand and gravel used as filling material and in concrete. Fuel minerals (oil, gas and coal) are used mainly as fuels but also to some extent (around 5 per cent) as feedstock for organic chemicals and materials, like plastics and asphalt. It can also be noticed that metals, except for iron (700 Mtonnes/year), are used in relatively small amounts: for example, aluminium 20 Mtonnes/year and copper 10 Mtonnes/year.

Certain specific industrial minerals are also used in large amounts, especially when em-ployed in high-volume building materials or as filling materials. Examples are limestone and various clays for cement production and gypsum. Raw materials for basic inorganic chemicals and fertilizers are used in relatively large amounts; some of them in much larger quantities than the non-iron metals. This applies to rock salt (NaCl), sulphur-containing minerals (S) and phosphate minerals (P), as well as nitrogen (N) from the air.

Globally, the harvested terrestrial biomass, about 9,000 Mtonnes/year is less than the excavated abiotic materials, but of the same order as the fossil fuels. The biomass is used for three main purposes: food/animal feed, materials and energy. Today these uses amount to 5,000, 2,000 and 2,000 Mtonnes/year respectively. The harvest of the sea in the form of fish catches (around 0.1 Mtonnes) is, on a weight basis, very small (around 2 per cent) compared to the terrestrial harvest. But it is still of great nutritional importance; it accounts for about 25 per cent of the human intake of animal protein.

8.5 Intake and outflow of materials to the technosphere

As mentioned earlier, of the totally mobilized materials, only a part is brought into society. This intake can be in the form of raw materials for production: either included in goods, infrastructure and other artefacts or consumed in the production of these artefacts or in the production of services. How is this intake of materials into the technosphere made up? The situation in industrialized countries can be illustrated by the account of the American materials balance given in Figure 3.3. The input is here the apparent consumption at the feedstock stage (that is, refined metal, ammonia, crushed stone). Compared to the MIPS material flow inputs, many of the categories are thus missing: air, water, soil erosion and overburden and refining wastes in the extractive industries.

In the United States, energy and construction minerals make up equal shares and together are about three-quarters of the apparent consumption of all materials. The harvest of biological materials corresponds to one-fifth. In industrialized countries, which have a high share of animal products in their diet, the agricultural harvest is dominated by animal fodder. Industrial minerals comprise 5 per cent and metals only 2 per cent, which are, once again, totally dominated by iron. Other metals together make up only 2 promille of the overall intake of materials.

From materials conservation it follows that the mobilized materials brought into the techno-sphere can either accumulate in the built technosphere or contribute to the outflow of materials from the technosphere. But, of course, the accumulated material will also, sooner or later, give rise to an outflow back to nature. There is a huge difference in these respects between and also within the various groups of materials.

Organic materials are to a large extent oxidised when used. Fuels are burnt giving rise to flue gases of mainly carbon dioxide and water which are immediately emitted to and dissipated in the atmosphere. The agricultural harvest is mainly used to feed animals and humans and is thus to a large extent dissipated in respiration or manure broken down in the soil. However, parts of organic materials are long-lived. There is an accumulation of wooden building materials in the technosphere. Part of organic waste, such as plastics and paper waste, can also stay intact for a long time in landfills.

Fertilizers, which make up a large part of the intake of chemical raw materials and which are used in association with organic materials, are spread dissipatedly into the soil. Also other chemicals, such as road salt, are dissipated in connection with their use.

During industrialization, the input of building materials has to a large extent accumulated in the built environment. Large amounts of sand, gravel, clay and other building materials for houses and roads have not yet been turned into waste. It is also possible that a large part of these materials will never be removed or considered a residue, but will be left when no longer in use as, for instance, the materials in old roads.

For various reasons, there is thus a huge difference in the materials input to society and the amount of solid residues generated and taken care of in one way or another. This can be illustrated with the materials balance for Sweden in 1991; see Figure. 3.5. The net intake to the techno-sphere was around 150 Mtonnes (165 Mtonnes, minus a net export of 12 Mtonnes), while the generated, mostly solid, residues were around 30 Mtonnes. Of these residues, around 10 Mtonnes were managed by the municipalities, while the rest were various production residues generated in industry.

In Germany, materials accumulation is around 1,000 Mtonnes/year according to Table 8.1. (Another estimate using the production of durable goods has arrived at around 700 Mtonnes/year.) A comparison with the total turnover of 5,400 Mtonnes/year (without water), suggests that the major part, or about three-quarters of the through-flow is dissipated. However, compared to the solid and liquid materials (without water) taken into the techno-sphere (thus excluding air, unused abiotic raw materials, and the erosion of soils), accumulation is a major part.

All the materials mentioned are today entirely or largely extracted from non-renewable resources. The creation of a sustainable society will require that the turnover of materials is reduced considerably, that renewable resources are used and that the ecological rucksacks are minimized.

8.6 The MIPS concept

Material extractions and emissions are changing natural material flows and biological cycles in ecosystems. Sooner or later every material-input becomes an output (waste, emissions).

Proxy methods are those where a single dimension is used to reflect the total environmental impact of a product or service. The ecological footprint 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. However, several of the categories in the footprint relies on material flows which are translated into area use, e.g. this is the case with energy. These categories thus relies on material intensities used in MIPS. This is further discussed in chapter 6.

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.

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. Measuring the inputs enables a rough approximation of the overall environmental burden. MIPS is an elementary measure to estimate the environmental impacts caused by a product or service. The whole life-cycle from cradle to cradle (extraction, production, use, waste/recycling) is considered. MIPS can be applied in all cases, where the environmental implications of products, processes and services need to be assessed and compared.

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.

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. Another problem is that the MI for a product is very different in different countries. In the present database mostly German data are given. Still several hundred MI indices are available. Examples of MI indices are found in Table 8.2.

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 ecoindicator 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.

8.7 The material intensities

A practical application of the MIPS Concept is called material intensity analysis (MAIA). Material intensity analyses are conducted on the micro-level (focussing specific products and services), as well as on the macro-level (focussing national economies). The Wuppertal Institute for Climate, Environment and Energy has given an introduction to Material Intensity Analysis based on the MIPS concept.

Table 8.2 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

The MIPS concept has been applied in multiple research projects, especially in Germany and Finland. Key examples include: Housing, mobility, glass packaging, food, household goods, tourism, leisure and sports activities. The MIPS tool also allows companies (SMEs) to increase profit by reducing material input for producing their products, processes or services. It helps SMEs to develop eco-innovative products and services and improve their material footprint. The tool provides information on the material intensity of produces, processes and services thus highlighting savings potentials and environmental impacts. As a result, it allows SMEs to choose green business options and to differentiate their products based on measured environmental characteristics.

The data on material intensities (MIT) needed to apply the MIPS tool is available at (http://wupperinst.org/uploads/tx_wupperinst/MIT_2013.pdf). They include data on different materials, fuels, transport services and food, listed according to the five inputs categories of the MIPS concept: These are abiotic and biotic materials, water, air and earth movement in agriculture and silviculture. The latter is differentiated between the two sub-categories “erosion” and “mechanical earth movement”. In case both values are available, the value for “mechanical earth” movement should be chosen.

MIT factors for the production of materials are accounted for a plant and include, if not further specified, all upstream processes (cradle to gate). The MIT factors form the basis for further analyses. In general, materials, fuels, transport services, etc. can only be assessed properly under concrete framework conditions, e.g. of a certain product. Data per kg of material are not suitable for giving a recommendation in favour of or against a specific material, fuel, etc. It is recommended to become familiar with the underlying MIPS concept before applying the presented values.

In different regions of the earth, fuels and raw materials as well as production processes may differ. Mineral raw materials are extracted from ores with different concentrations. Agricultural production depends on fluctuating crop yields due to – amongst others – regionally differing and annually fluctuating climate conditions. It is therefore necessary to use the values relevant for the specific region. However, a great number of materials are traded throughout Europe and even throughout the World. Furthermore, the liberalization of the European energy markets is increasingly diminishing the importance of national borders.

A number of materials is re-used to a relevant extent. As far as possible, “typical” shares of secondary materials were taken into account or values for primary and secondary materials were given. Especially with relatively new materials, there is often a discrepancy between possible recycling quotas and input quotas for secondary materials in production as a result of the low amount of scrap or waste materials in relation to the production quantity. The input quotas of the production are decisive for the MIT values, since only they allow to record the use of resources in production. However, it is possible to analyse developments of higher input quotas of secondary materials.

All data have been determined to the best knowledge of the Wuppertal Institute. For the most part, however, they are based on information from third parties or literature. No liability is assumed for the accuracy of the data.

Chapter 8 sources:

Baltic University publication A Sustainable Baltic Region, Book 3 by Sten Karlsson Chapter 3 Man and materials flows – Towards sustainable materials management http://www.balticuniv.uu.se/index.php/boll-online-library/819-a-sustainable-baltic-region

Baltic University publication Environmental Management, Book 3 Product Design and Life Cycle Assessment by Ireneusz Zbicinski, John Stavenuiter, Barbara Kozlowska, and Hennie van de Coevering: Chapter 7 Ready-made Methods forLife Cycle Impact Assessment http://www.balticuniv.uu.se/index.php/boll-online-library/828-em-3-product-design-and-life-cycle-assessment-

Wuppertal Institute for Climate, Environment and Energy:

MIPS on-line

http://wupperinst.org/en/projects/topics-online/mips/

On-line service Material intensity of materials, fuels, transport services, food

http://wupperinst.org/uploads/tx_wupperinst/MIT_2014.pdf

Chapter 9
Material flow analysis and its applications

9.1 What is Material Flow Analysis (MFA)?

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process. It is this distinct characteristic of MFA that makes the method attractive as a decision-support tool in resource management, waste management, and environmental management.

An MFA delivers a complete and consistent set of information about all flows and stocks of a particular material within a system. Through balancing inputs and outputs, the flows of wastes and environmental loadings become visible, and their sources can be identified. The depletion or accumulation of material stocks is identified early enough either to take countermeasures or to promote further buildup and future utilization.

Anthropogenic systems consist of more than material flows and stocks (Fig. 9.1). Energy, space, information, and socioeconomic issues must also be included

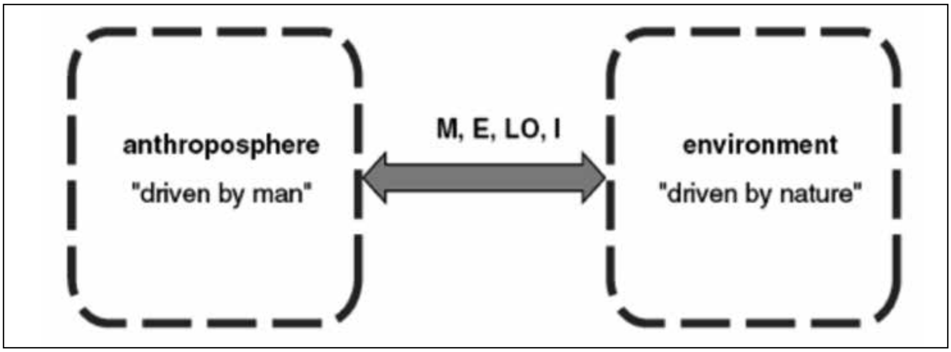


Figure 9.1 The two systems anthroposphere and environment exchange flows of materials (M), energy (E), living organisms (LO), and information (I). (Source: Practical handbook of material flow analysis by Paul H. Brunner and Helmut Rechberger).

if the anthroposphere is to be managed in a responsible way. MFA can be performed without considering these aspects, but in most cases, these other factors are needed to interpret and make use of the MFA results. Thus, MFA is frequently coupled with the analysis of energy, economy, urban planning, and the like.

The term material stands for both substances and goods. In chemistry, a substance is defined as a single type of matter consisting of uniform units. If the units are atoms, the substance is called an element, such as carbon or iron; if they are molecules, it is called a chemical compound, such as carbon dioxide or iron chloride.

Goods are substances or mixtures of substances that have economic values assigned by markets. The value can be positive (car, fuel, wood) or negative (municipal solid waste, sewage sludge). In economic terms, the word goods is more broadly defined to include immaterial goods such as energy (e.g., electricity), services, or information.

In MFA terminology, however, the term goods stands for material goods only. Nevertheless, the link between goods as defined by MFA and other goods as used by economists can be important when MFA is applied, for example, for decisions regarding resource conservation.

A process is defined as a transport, transformation, or storage of materials. The transport process can be a natural process, such as the movement of dissolved phosphorous in a river, or it can be man-made, such as the flow of gas in a pipeline or waste collection. The same applies to transformations (e.g., oxidation of carbon to carbon dioxide by natural forest fires vs. man-made heating systems) and storages (e.g., natural sedimentation vs. man-made landfilling).

Stocks are defined as material reservoirs (mass) within the analysed system, and they have the physical unit of kilograms. A stock is part of a process comprising the mass that is stored within the process. Stocks are essential characteristics of a system's metabolism. For steady-state conditions (input equals output), the mean residence time of a material in the stock can be calculated by dividing the material mass in the stock by the material flow in or out of the stock. Stocks can stay constant, or they can increase (accumulation of materials) or decrease (depletion of materials) in size.

Processes are linked by flows (mass per time) or fluxes (mass per time and cross section) of materials. Flows/fluxes across systems boundaries are called imports or exports. Flows/fluxes of materials entering a process are named inputs, while those exiting are called outputs.

A system comprises a set of material flows, stocks, and processes within a defined boundary. The smallest possible system consists of just a single process. Examples of common systems for investigations by MFA are: a region, a municipal incinerator, a private household, a factory, a farm, etc. The system boundary is defined in space and time. It can consist of geographical borders (region) or virtual limits (e.g., private households, including processes serving the private household such as transportation, waste collection, and sewer system). When the system boundary in time is chosen, criteria such as objectives, data availability, appropriate balancing period, residence time of materials within stocks, and others have to be taken into account.

In addition to the basic terms necessary to analyse material flows and stocks, the notion of Activity is useful when evaluating and designing new anthropogenic processes and systems. An activity comprises a set of systems consisting of flows, stocks, and processes of the many materials that are necessary to fulfil a particular basic human need, such as to nourish, to reside, or to transport and communicate.

Analysing material flows associated with a certain activity allows early recognition of problems such as future environmental loadings and resource depletions. One of the main questions for the future development of mankind will be "Which sets of processes, flows, and stocks of goods, substances, and energy will enable long-term, efficient, and sustainable feeding of the increasing global population?" Equally important is the question, "How to satisfy the transportation needs of an advanced global population without compromising the future resources of mankind?"

MFA can help to identify major changes in material flows. Thus, MFA is a tool to evaluate existing systems for food production, transportation, and other basic human needs, as well as to support the design of new, more efficient systems.

9.2 Leontief's economic input-output methodology

Wassily W. Leontief (1906–1999) was an American economist of Russian origin. His research was focused on the interdependence of anthropogenic production systems. He searched for analytical tools to investigate the economic transactions between the various sectors of an economy. One of his major achievements, for which he was awarded the 1973 Nobel Prize in economic sciences, was the development of the input-output method in the 1930s. At the core of the method are so-called input-output tables. These tables provide a method for systematically quantifying the mutual interrelationships among the various sectors of a complex economic system. They connect goods, production processes, deliveries, and demand in a stationary as well as in a dynamic way. The production system is described as a network of flows of goods (provisions) between the various production sectors.

Input-output analysis of economic sectors has become a widespread tool in economic policy making. It proved to be highly useful for forecasting and planning in market economies as well as in centrally planned economies, and it was often applied to analyse the sudden and large changes in economies due to restructuring. In order to investigate the effect of production systems on the environment, the original method was later expanded to include production emissions and wastes. More recently, the input-output method has been incorporated into Life Cycle Assessment, LCA, to establish the economic input–output LCA method. The input-output tables for some 500 sectors in USA economy are available on the Internet at the Green Design Institute of Carnegie Mellon University, which operationalized Leontief's method in the mid-1990s (http://www.eiolca.net/).

This expansion provides a means of assessing the relative emissions and resource consumption of different types of goods, services, and industries. The advantage of using input-output methodology for LCA is the vast amount of available information in the form of input-output tables for many economies. This information can be used for LCA as well.

9.3 Analysis of city metabolism

Santorio Santorio (1561–1636) analyzed the physiological, "inner" metabolism of humans, but this is only a minor part of the modern anthropogenic turnover of materials. The "outer" metabolism, consisting of the use and consumption of goods not necessary from a physiological point of view, has grown much larger than the inner metabolism. Hence, in places with a high concentration of population and wealth such as modern urban areas, large amounts of materials, energy, and space are consumed. Today, most cities are rapidly growing in population and size, and they comprise a large and growing stock of materials.

The first author to use the term metabolism of cities was Abel Wolman in 1965. He used available U.S. data on consumption and production of goods to establish per capita input and output flows for a hypothetical American city of 1 million inhabitants. He linked the large amounts of wastes that are generated in a city to its inputs. The complex urban metabolism has also fascinated other authors, who have developed more specific methods to quantify the urban turnover of energy and materials and investigated the effects of the large flows on resource depletion and the environment. Two prominent examples are the studies of Brussels by Duvigneaud and Denayeyer-De Smet and of Hong Kong by Newcombe et al.

In 1975, Duvigneaud and Denayeyer-De Smet analyzed the city of Brussels using natural ecosystems as an analogy. They assessed the total imports and exports of goods such as fuel, construction materials, food, water, wastes, sewage, emissions, etc. in and out of the city and established an energy balance. The authors concluded that Brussels was highly dependent on its hinterland, with the city importing all its energy from external sources. Since solar energy theoretically available within the city equalled Brussels's entire energy demand, this dependency could be reduced by shifting from fossil fuels to solar energy. Water produced within the city by precipitation is not utilized; all drinking water is imported. Materials such as construction materials and food are not recycled after their use and are exported as wastes. The linear flows of energy and materials result in high pollution loads that deteriorate the quality of the water, air, and soil of the city and its surroundings.

The authors point out the necessity of changing the structures of cities in a way that improves the utilization of energy and materials, creates material cycles, and reduces losses to the environment. Similar to Santorio's observation regarding the relationship of metabolism to the health of a person, the authors conclude that efforts to ensure the continual welfare of a city must be guided by knowledge of the city's metabolism. They recognize that only an interdisciplinary approach will succeed in analysing, defining, and implementing the necessary measures of change.

At about the same time, in the beginning of the 1970s, Newcombe and colleagues started their investigation into the metabolism of Hong Kong. This Asian city was experiencing a rapid transition period of high population growth and intense economic development due to its privileged position at the interface between Western trade and Eastern production and manufacturing. Hong Kong was an ideal case for metabolic studies, since city limits coincide more or less with state boundaries. Thus, in contrast to the Brussels study, economic data from state statistics were available for an accurate assessment of the import and export goods of Hong Kong. Also, Hong Kong differs from Brussels in its high population density and its lower per capita income and material throughput. The authors found that the material and energy used for Hong Kong's infrastructure was about one order of magnitude smaller than in more highly developed cities. They concluded that a worldwide increase in material consumption to the level of modern cities would require very large amounts of materials and energy and would have negative impacts on global resources and the environment. They also stated that in order to find sustainable solutions for the future development of cities, it is necessary to know the urban metabolism. Thus, it is important to be able to measure the flows of goods, materials, and energy through urban systems. In 1997, Konig revisited the metabolism of Hong Kong, showing the impact of the large increase in material turnover on the city and its surroundings.

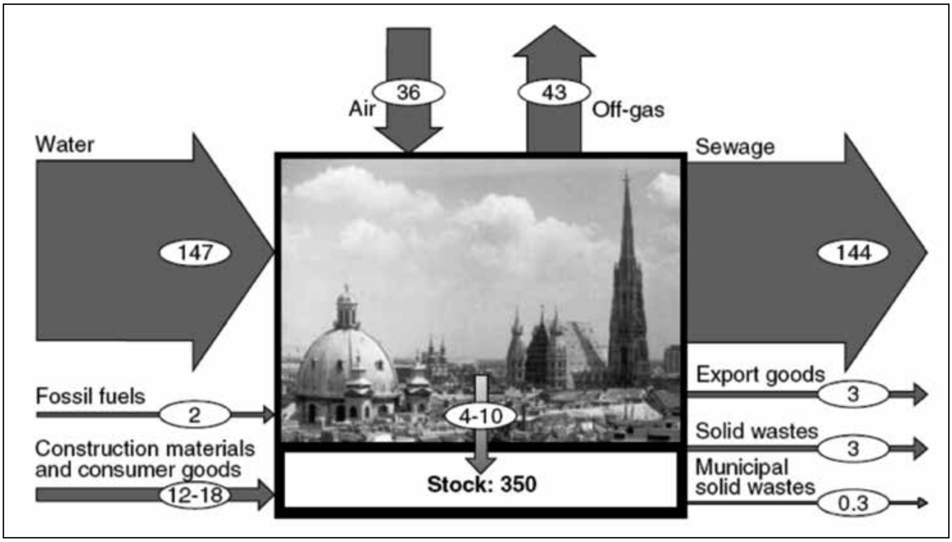


Figure 9.2 Materials consumption in Vienna. In the 1990s, about 200 tons of materials were consumed per capita per year in the city of Vienna, and somewhat less than this amount left the city in a linear way. The small difference of 4 to 10 t/capita and yr accumulates, resulting in a continuous growth of the stock of 350 t/capita that doubles in 50 to 100 years. Basically, the modern anthropogenic metabolism is a linear-throughput reactor, with less than 1% of materials being involved in regional cycles. (Source: Brunner, P.H. and Rechberger, H., Anthropogenic metabolism and environmental legacies, in Encyclopedia of Global Environmental Change, Vol. 3, Munn, T., Ed., John Wiley & Sons, West Sussex, U.K., 2001.)

9.4 Metabolism of the anthroposphere

Baccini, Brunner, and Bader extended material flow analysis by defining a systematic and comprehensive methodology and by introducing the concepts of "activity" and "metabolism of the anthroposphere" Their main goals were (1) to develop methods to analyse, evaluate, and control metabolic processes in man-made systems and (2) to apply these methods to improve resource utilization and environmental protection on a regional level. Engaged in solving waste-management problems, they recognized that the so-called filter strategy at the back end of the materials chain is often of limited efficiency. It is more cost-effective to focus on the total substance flow and not just on the waste stream.

Their integrated approach is directed toward (1) the turnover of materials and energy, (2) activities and structures, and (3) the interdependency of these aspects in regions. In the project SYNOIKOS, Baccini, collaborating with Oswald and a group of architects, combined physiological approaches with structural approaches to analyse, redefine, and restructure urban regions. This project shows the full power of the combination of MFA with other disciplines to design new, more efficient, and sustainable anthropogenic systems.

Lohm, originally an entomologist studying the metabolism of ants, and Bergbäck were also among the first to use the notion "metabolism of the anthroposphere" to study metabolic processes by MFA. In their pioneering study of the metabolism of Stockholm, they focused on the stock of materials and substances in private households and the corresponding infrastructure. They identified the very large reservoir of potentially valuable substances, such as copper and lead, within the city. Lohm and Bergbäck drew attention to urban systems in an effort to prevent environmental pollution by the emissions of stocks and to conserve and use the valuable substances hidden and hibernating in the city.

Fischer-Kowalsky et al. employed a similar set of tools and expanded the methodology by adopting approaches used in the social sciences. They coined the term colonization to describe the management of nature by human societies and investigated the transition from early agricultural societies to today's enhanced metabolism.

Wackernagel et al. developed a method to measure the ecological footprints of regions, a method that is based, in part, on MFA. They concluded that regions in affluent societies use a very large "hinterland" for their supply and disposal, and they suggest the need to compare and ultimately reduce the ecological footprints of regions. They argue that our concept of progress must be redefined.

The "progress" observed in most of today's societies does not translate to an increase in the general welfare, if measured properly, and thus there is a need to change the direction of development. In other works also based on MFA, both Schmidt-Bleek and von Weizsäcker from the Wuppertal Institute for Climate and Energy concluded that, considering environmental loadings and resource conservation, the turnover of materials in modern economies is much too high. In order to achieve sustainable development, they recommend a reduction of material flows by a factor of four to ten. Bringezu, from the same group in Wuppertal, established a platform for the discussion of materials-accounting methodology, called "Conaccount," that was joined by many European research groups.

The Wuppertal Institute also started to collect and compare information about national material flows in several countries from Europe and Asia and in the U.S. In The Weight of Nations, Matthews and colleagues document and compare the material outflows from five industrial economies (Austria, Germany, Japan, Netherlands, and the U.S.). They developed physical indicators of material flows that complement national economic indicators, such as gross domestic product (GDP). In 2000, a group of researchers from the Centre for Industrial Ecology at

Yale University launched a several-years-long project to establish material balances for copper and zinc on national, continental, and global levels (the stocks and flows project [STAF]).

9.5 Applications of MFA

The historical development shows that MFA has been applied as a basic tool in such diverse fields as economics, environmental management, resource management, and waste management.

The environment is a complex system comprising living organisms, energy, matter, space, and information. The human species, like all other species, has used the environment for production and disposal. We produce food and shelter - drawing on soil, water, and air - and in return we gave back wastes such as faeces, exhaust air, and debris. Environmental engineering has been described as (1) the study of the fate, transport, and effects of substances in the natural and engineered environments and (2) the design and realization of options for treatment and prevention of pollution.

The objectives of management and engineering measures are to ensure that (1) substance flows and concentrations in water, air, and soil are kept at a level that allows the genuine functioning of natural systems and (2) the associated costs can be carried by the actors involved.

MFA is used in a variety of environmental-engineering and management applications, including environmental-impact statements, remediation of hazardous-waste sites, design of air-pollution control strategies, nutrient management in watersheds, planning of soil-monitoring programs, and sewage-sludge management. All of these tasks require a thorough understanding of the flows and stocks of materials within and between the environment and the anthroposphere. Without such knowledge, the relevant measures might not be focused on priority sources and pathways, and thus they could be inefficient and costly.

MFA is also important in management and engineering because it provides transparency. This is especially important for environmental-impact statements. Emission values alone do not allow cross-checking when a change in boundary conditions (e.g., change in input or process design) is appropriate to meet regulations. However, if the material balances and transfer coefficients of the relevant processes are known, the results of varying conditions can be cross-checked.

There are clear limits to the application of MFA in the fields of environmental engineering and management. MFA alone is not a sufficient tool to assess or support engineering or management measures. Nevertheless, MFA is an indispensable first step and a necessary base for every such task, and it should be followed by an evaluation or design step.

9.6 Resources management

There are two kinds of resources: first, natural resources such as minerals, water, air, soil, information, land, and biomass (including plants, animals, and humans), and second, human-induced resources such as the anthroposphere as a whole, including materials, energy, information (e.g., "cultural heritage," knowledge in science and technology, art, ways of life), and manpower. The human-induced or so-called anthropogenic resources are located in (1) private households, agriculture, industry, trade, commerce, administration, education, health care, defence, and security systems and (2) infrastructure and networks for supply, transportation and communication, and disposal. Given the large-scale exploitation of mines and ores, many natural resources are massively transformed into anthropogenic resources.

Thus, the growing stocks of the anthroposphere will become increasingly more important as a resource in the future. Resource management comprises the analysis, planning and allocation, exploitation, and upgrading of resources. MFA is of prime importance for analysis and planning. It is the basis for modelling resource consumption as well as changes in stocks, and therefore it is important in forecasting the scarcity of resources. MFA is helpful in identifying the accumulation and depletion of materials in natural and anthropogenic environments. Without it, it is impossible to identify the shift of material stocks from "natural" reserves to "anthropogenic" accumulations. In addition, if MFA is performed in a uniform way at the front and back end of the anthropogenic system, it is instrumental in linking resources management to environmental and waste management. It shows the need for final sinks and for recycling measures, and it is helpful in designing strategies for recycling and disposal.

Balancing all inflows and outflows of a given stock yields information on the time period until the stock reaches a critical state of depletion or accumulation. This could be the slow exhaustion of available phosphorous in agricultural soil due to the lack of appropriate fertilizer, or it could be the unnoticed build-up of valuable metals in a landfill of incinerator ash and electroplating sludge. It is difficult to estimate the change in the stock by direct measurement, especially for stocks with a high variability in composition and slow changes in time. In such cases, it is more accurate and cost effective to calculate critical time scales (the time when a limiting or reference value is reached) by comparing the difference between input and output to the stock from its flow balance. Direct measurement requires extensive sampling programs with much analysis, and the heterogeneity of the flows produces large standard deviations of the mean values. Thus, it takes large differences between mean values until a change becomes statistically significant. A slow change in a heterogeneous material can be proved on statistical grounds only over long measuring periods. As a result, MFA is better suited and more cost-effective than continuous soil monitoring in early recognition of changes in resource quality, such as harmful accumulations in the soil.

The use (and preferably conservation) of resources to manufacture a particular good or to render a specific service is often investigated by LCA. The result of an LCA includes the amount of emissions and the resources consumed. Since MFA is the first step of every LCA, MFA is also a base for resource conservation.

The quality and price of a resource usually depends on the substance's concentration. Thus, it is important to know whether a natural or anthropogenic process concentrates or dilutes a given substance. MFA is instrumental in the application of such evaluation tools as statistical entropy analysis, which is used to compare the potential of processes and systems to accumulate or dilute valuable or hazardous substances.

9.7 Waste management

Waste management takes place at the interface between the anthroposphere and the environment. The definition and objectives of waste management have changed over time and are still changing. The first signs of organized waste management appeared when people started to collect garbage and remove it from their immediate living areas. This was an important step regarding hygiene and helped to prevent epidemics. These practices were improved over the centuries.

However, dramatic changes in the quantity and composition of wastes during the 20th century caused new problems. First, the emissions of the dumping sites (landfills) polluted groundwater and produced greenhouse gases. Second, landfill space became scarce in densely populated areas. Even the concept of sanitary landfilling could not solve these problems in the long run. Today, waste management is an integrated concept of different practices and treatment options comprising prevention and collection strategies; separation steps for producing recyclables or for subsequent processing using biological, physical, chemical, and thermal treatment technologies; and different landfill types.

People now have the opportunity (or, in some places, the duty) to separate paper, glass, metals, biodegradables, plastics, hazardous wastes, and other materials into individual fractions. The goals of modern waste management are to:

- Protect human health and the environment
- Conserve resources such as materials, energy, and space
- Treat wastes before disposal so that they do not need aftercare when finally stored in landfills

The last goal is also known as the final-storage concept and is part of the precautionary principle: the wastes of today's generation must not impose an economic or ecological burden to future generations. Similar goals can be found in many instances of modern waste-management legislation, which were written to comply with the requirements for sustainable development. The aforementioned goals make it clear that the focus in waste management is not necessarily on goods (paper, plastics, etc.) or on functions of materials (e.g., packaging). The focus is on the nature of the substances.

Hazardous substances threaten human health. The threat occurs when municipal solid waste (MSW) is burned in poorly equipped furnaces and volatile heavy metals escape into air. It is not the good leachate of a landfill that imposes danger to the groundwater. The danger resides in the cocktail of hazardous substances in the leachate of the landfill. The fact that a material has been used for packaging is irrelevant for recycling. What is important is its elemental composition, which determines whether it is appropriate for recycling.

Hence, advanced waste-management procedures are implemented to control and direct the disposition of substances at the interface between the anthroposphere and the environment to achieve the following two goals.

1. Materials that can be recycled without inducing high costs or negative substance flows should be recycled and reused. Negative flows can appear as emissions or by-products during the recycling process. The recycling process itself can also lead to enrichment of pollutants in goods and reservoirs. For example, the recycling process can increase heavy metal contents in recycled plastics, or it can lead to accumulation of metals in the soil when sewage sludge is applied to agricultural fields.
2. Non-recyclables should be treated to prevent the flow of hazardous substances to the environment. A tailor-made final sink - defined as a reservoir where a substance resides for a long period of time (>10,000 years) without having a negative impact on the environment - should be assigned for each substance.

MFA is a valuable tool in substance management because it can cost-efficiently determine the elemental composition of wastes exactly. This information is crucial if the goal is to assign a waste stream to the best-suited recycling/treatment technology and to plan and design new waste-treatment facilities.

For example, mixed plastic wastes that cannot be recycled for process reasons can be used as a secondary fuel in industrial boilers as long as their content of heavy metals and other contaminants is not too high.

MFA is also helpful in investigating the substance management of recycling/treatment facilities. For instance, substance control by an incinerator is different from substance control by a mechanical–biological treatment facility. Such information is a prerequisite for the design of a sustainable waste-management system.

Nordrhein-Westfalen (Germany) is the first region that requires MFA by legislation as a standard tool in waste-management planning.

Finally, MFA can contribute to the design of better products that are more easily recycled or treated once they become obsolete and turn into "waste." These practices are known as design for recycling, design for disposal, or design for environment.

An MFA-based total material balance shows whether given goals have been achieved. An MFA balance also identifies the processes and flows that have the highest potential for improvements.

Waste management is an integral part of the economy. Some experts who have experience with MFA suggest that waste management should be replaced by materials and resource management. They assert that controlling the material flows through the total economy is more efficient than the current practice of separating management of wastes from the management of production supply and consumption.

9.8 Human activities

Regardless of a community's social, cultural, technical, or economic development, there is a set of basic human needs such as to eat, to breath, to reside, to communicate, to transport, and others. The main goal of a sustainable economy is to satisfy these needs best at the least cost. An activity is defined as comprising all relevant processes, flows, and stocks of goods and substances that are necessary to carry out and maintain a certain human need. The purpose of defining activities is to facilitate the analysis of a given way of fulfilling human needs, to evaluate the constraints and optimization potentials, and to suggest strategies and measures for optimizing the way the needs are satisfied.

The most important activities can be defined as follows. (Note that this list is not complete. Additional activities such as "leisure," "health and sports," etc.

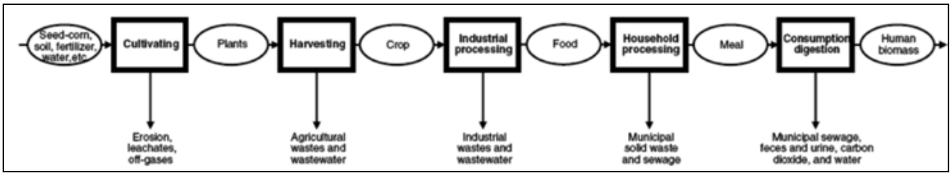


Figure 9.3 Process chain of main processes associated with the activity "to nourish." Required goods to operate the processes (energy, machinery, tools, etc.) are omitted.1 (Source: Baccini, P. and Brunner, P.H., Metabolism of the Anthroposphere, Springer, New York, 1991.)

can be defined, if necessary, to analyse and solve a particular resource-oriented problem.):

To nourish: This activity comprises all processes, goods, and substances used to produce, process, distribute, and consume solid and liquid food. "To nourish" starts with agricultural production (e.g., the goods "seed corn," "water," "air," "soil," "fertilizer" and the process "crop raising," e.g., beans), food production (e.g., the process "cannery," the good "canned beans"), distribution (e.g., the process "grocery"), consumption (e.g., the processes "storage," "preparation," and "consumption" of canned beans in private households), and ends with the release of off-gases (breath), faeces and urine, and solid wastes (can, leftover beans) to the atmosphere and the waste- and wastewater-treatment systems. These systems already belong to the activity "to clean," as discussed in the following paragraph. Figure 9.3 shows the main processes for the activity.

To reside and work: This activity comprises all processes that are necessary to build, operate, and maintain residential units and working facilities. Important processes are "building construction," "operation and maintenance of buildings," "machine construction," "operation and maintenance of machinery," "manufacture of furniture and household appliances," "manufacture of clothing and leisure appliances," and "consumption." Table 9.1 gives an example for subprocesses and related goods for the process "building construction." Figure 9.6 outlines a flowchart for the activity "to reside and work."

The functions and services that are expected from a building are manifold. One is that it should provide an agreeable temperature inside. This can be realized by different heating and cooling systems, different types of wall construction, and the use of different materials for better insulation. But other approaches are also possible to fulfil the service "agreeable body temperature" during the cool season. Besides measures for the outer skin (the wall), a combination of reduced heating and wearing a pullover (insulation of the inner skin) can also fulfil the task. All three approaches (heating, insulation, clothes) result in different materials and energy consumption.

Table 9.1. Subprocesses and Their Input and Output Goods for the Process "Building Construction"

Process	Subprocess	Inputs	Outputs
Building construction	concrete production, steel and metal production, quarry, lumber mill, energy supply	gravel, sand, stone, limestone, marl, metal ores, wood, fuels, water, air	buildings, construction and demolition waste, wastewater, off-gas

To clean: In anthropogenic processes, "wanted" materials are often separated from "unwanted" materials. When sugar is produced from sugar cane, sucrose is separated from cellulose and impurities. In dry cleaning, dirt is removed from the surface of clothes by organic solvents such as perchloroethylene. People need to remove dirt and sweat from their body surfaces. Also, they need to remove materials not useful for their metabolism and wastes from their body, such as carbon dioxide in breath, salts in urine, or undigested biomass in faeces. Since many of these processes are called "cleaning," the separation of valuable from useless materials has been defined as the activity "to clean." It is an essential activity for human beings, since it is necessary for everybody to keep material input and output in a balance. Examples for cleaning processes on the individual level are "private and commercial laundry" (Figure 9.5), "dishwashing," and "housecleaning"; on the industrial level there is "refinery," "metal purification," and "flue-gas treat-

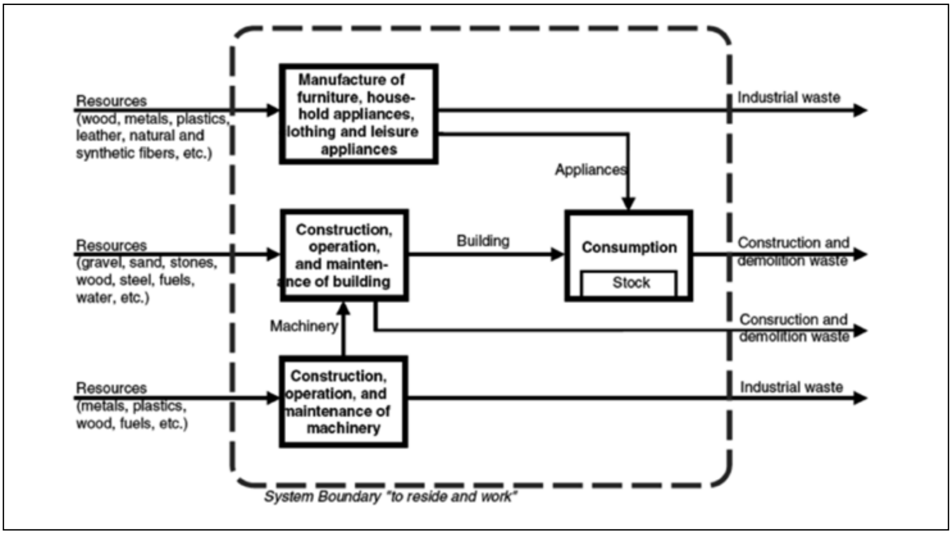


Figure 9.4 Relevant processes and goods for the activity "to reside and work." Only solid wastes are indicated.

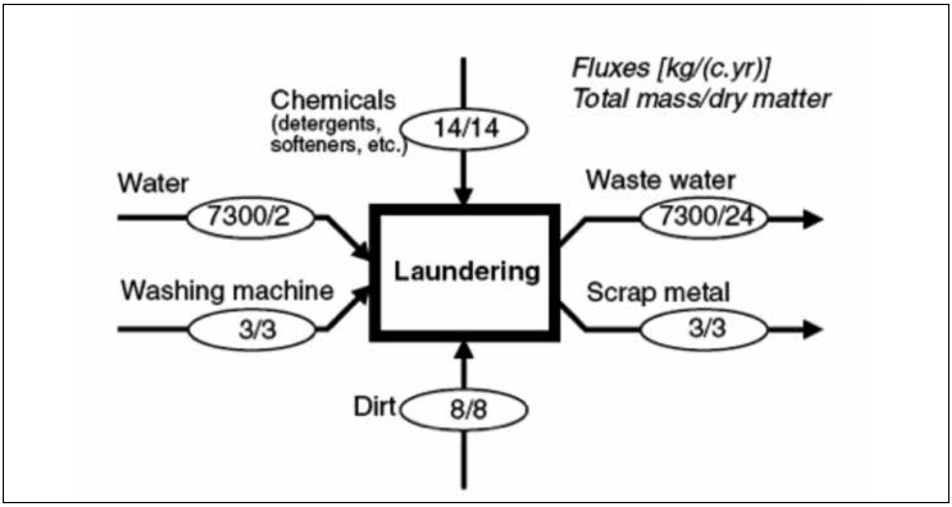


Figure 9.5 Mass flows of goods for the activity to clean through the process laundry, which is a subprocess of the process household. About 100 kg of water are needed to separate 1 kg of dirt from textiles (kg/capita/year; left side of figure: total mass; right side of figure: dry matter).1 (Source: Baccini, P. and Brunner, P.H., Metabolism of the Anthroposphere, Springer, New York, 1991.)

ment"; and on the community level there is "sewage and waste treatment" and "public cleaning." "To clean" is also a very important activity for public health.

9.7 Anthroposphere's flows

The human sphere of life - a complex system of energy, material, and information flows in space - is called the "anthroposphere." It is part of planet Earth and contains all processes that are driven by mankind. The anthroposphere can be seen as a living organism. In analogy to the physical processes in plants, animals, lakes, or forests, the "metabolism" of the anthroposphere includes the uptake, transport, and storage of all substances; the total biochemical transformation within the organism; and the quantity and quality of all off-products such as flue gas, sewage, and wastes.

The complementary part to the anthroposphere is designated as the environment. The anthroposphere interacts with the environment via extraction of resources (air, water, and minerals) and emission of off-products and wastes. The anthroposphere can be defined as part of any region where human activities take place. As a first step, the anthroposphere can be divided into the four compartments (main processes in Fig. 9.6):

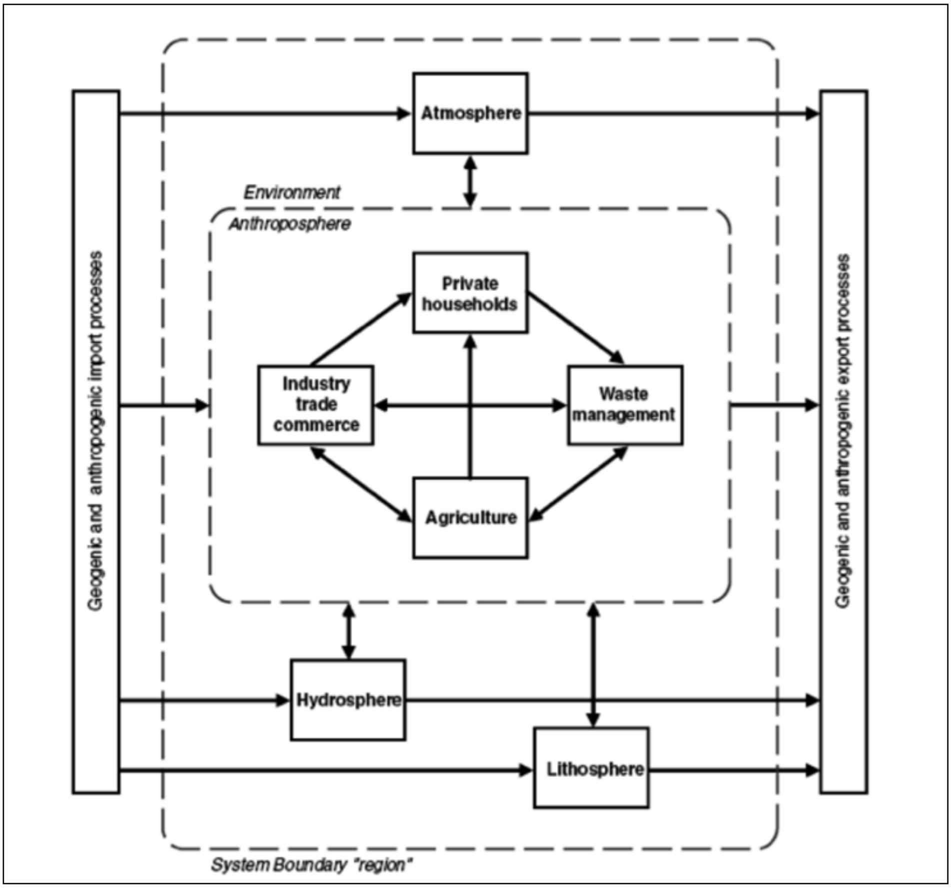


Figure 9.6 A region where anthropogenic activity takes place can be divided into the subsystems "anthroposphere" and "environment." Exchange of materials takes place within the subsystems as well as between the subsystems and processes outside the region.

1. Agriculture
2. Industry, trade, and commerce
3. Private households (consumption)
4. Waste management

All along the anthropogenic process chain there is exchange of materials and energy with the environment, which comprises four compartments: atmosphere, hydrosphere, pedosphere, and lithosphere. Often, terms such as water, air, and soil (for pedosphere) are used synonymously. Some authors use the terms technosphere or biosphere instead of anthroposphere.

Sometimes the interface between anthroposphere and environment is not clear. For example, a soil that is used by humans can be regarded as a part of the anthroposphere as well as of the environment. Hence, the definition of the anthroposphere is somewhat subjective. Some authors claim that all soils belong to the anthroposphere because anthropogenic trace substances have been detected in all soils on Earth; there are no soils anymore that are in a natural, uninfluenced state, and thus they do not belong to the environment anymore. Other authors include only those soils in the anthroposphere that are actively managed by mankind. In MFA practice, such allocation problems are of little relevance. They should be acknowledged but not overemphasized. The term metabolism is used in many different fields and contexts. Initially it was used to name the turnover, which is the uptake, internal transformation, and emission of energy and matter within living bodies (organisms). Later on, due to the compelling analogy between man-made systems and biological organisms, the term metabolism was applied to anthropogenic as well as geogenic (natural) processes and systems.

In MFA, metabolism of a system stands for the transfer, storage, and transformation of materials within the system and the exchange of materials with its environment. Metabolism is applied to anthropogenic as well as geogenic (natural) processes and systems. Patzel and Baccini13 elaborate the pros and cons of the term with regard to literal and metaphoric usage as compared with household and physiology and give their preference to physiology. It is likely that both terms, metabolism and physiology, will be used synonymously in future.

Material flow analysis (MFA) is a method to describe, investigate, and evaluate the metabolism of anthropogenic and geogenic systems. MFA defines terms and procedures to establish material balances of systems.

Chapter 9 sources:

Practical handbook of material flow analysis by Paul H. Brunner and Helmut Rechberger. 320 p. © 2004 by CRC Press LLC. ISBN 1-5667-0604-1

Baccini, P. and Brunner, P.H., Metabolism of the Anthroposphere, Springer, New York, 1991

IV
Towards Sustainable Materials Management

Chapter 10
Towards sustainable materials management

10.1 Socio-ecological principles for sustainability

Holmberg et al. [1994] have formulated four general principles for the exchange flows between society and nature and for the manipulation that has to be fulfilled in order to achieve a sustainable interaction between society and nature (Figure 10.1). The first principle deals with the flow and use of substances from the lithosphere and the second with flows of substances that are produced within society. The third principle deals with the extraction of resources from the ecosphere and the manipulation of the ecosphere and, finally, the fourth principle deals with the metabolism and resources use within society. Figure 10.2 shows the foci of the principles in relation to the society-nature interactions.

These principles operationalize the concept of sustainability as it was presented in the Brundtland report. They can be viewed as a more elaborate definition of sustainability and, as such, they can serve as a platform for discussions

Box 10.1. Waste manegemant and materials manegement

It is no longer enough to focus on waste handling and emission control and be left with making the best possible use of whatever is discarded from the technosphere. We must produce an overriding materials strategy involving all the important parts of societal mobilizations and turnover of materials. We need to turn from a waste management strategy to a materials management strategy.

In what way do we have to adapt our physical societal metabolism in order to approach sustainability? In the Brundtland report sustainability is described as ”meeting the needs of the present generation without compromising the ability of future generations to meet their own needs.” As a general rule, we should avoid systematic changes of the ecosphere that threaten the long-term survival of humankind on Earth. This leads to restrictions on our exchange of materials with nature and to our manipulation of nature.

This chapter on dematerialisation is taken from Chapter 4 Man and materials flows – Towards sustainable materials management from the Baltic University publication A Sustainable Baltic Region, Book 3 by Sten Karlsson from the Department of Physical Resource theory of Chalmers University of Technology and University of Gothenburg, , Gothenburg Sweden where also John Holmberg, mentioned in the text is working. References and additional pictures are available in the original text.

PRINCIPLE 1	PRINCIPLE 2	PRINCIPLE 3	PRINCIPLE 4
Substances extracted from the lithosphere must not systematically accumulate in the ecosphere.	Society-produced substances must not systematically accumulate in the ecosphere.	The physical conditions for production and diversity within the eco-sphere must not systematically be deteriorated.	The use of resources must be efficient and just with respect to meeting human needs.

Figure 10.1 Physical principles for sustainability. Based on the characterization of the interaction between society and nature,one can identify general criteria for sustainability. These are formulated into guiding principles for materials flows, to be used by planners and decision-makers aiming at development towards sustainability (Source: Holmberg et al in A Sustainable Baltic Region, Book 3 by Sten Karlsson,BUP Press 1997)

on sustainability issues, to be used in planning processes and in the formulation of policies at various levels of society. Practical experience from companies and local authorities in many countries, especially as managed by the Natural Step Foundation, has shown that the socio-ecological principles function well when making strategic decisions. More than 40 Swedish municipalities and many larger Swedish companies use these principles in their strategic planning process.

10.2 Principles 1 and 2: Turnover in balance

Principle 1 means that substances from the lithosphere must not be spread in the eco-sphere faster than various processes, for example, sedimentation processes, withdraw them from the ecosphere and return them to the lithosphere. If the input to the ecosphere (from the lithosphere and the technosphere) exceeds the sedimentation processes, these substances will accumulate in the ecosphere. Because of the complexity and delay mechanisms of chemical and physical processes in the ecosphere, it is often hard to say at what level of concentration such substances cause an environmental effect. In fact, every substance has its limit (often unknown) above which it will cause damage in various parts of the ecosphere.

For many chemical elements, anthropogenic weathering (mining) exceeds natural weathering. Even if materials extracted from the lithosphere by mining do not directly enter the ecosphere, there is continuous leakage of elements, for example, metals, from the accumulated pool in the technosphere.

Besides metals, there are other lithospherical substances that cause large environmental problems. Compared with that of today, a radically decreased use of fossil fuels is necessary in order not to accumulate too much of the greenhouse gas carbon dioxide in the atmosphere. This accumulation has led to that the concentration of carbon dioxide in the atmosphere has increased dramatically, presently by 50%. Acidification is another consequence of the extensive burning of

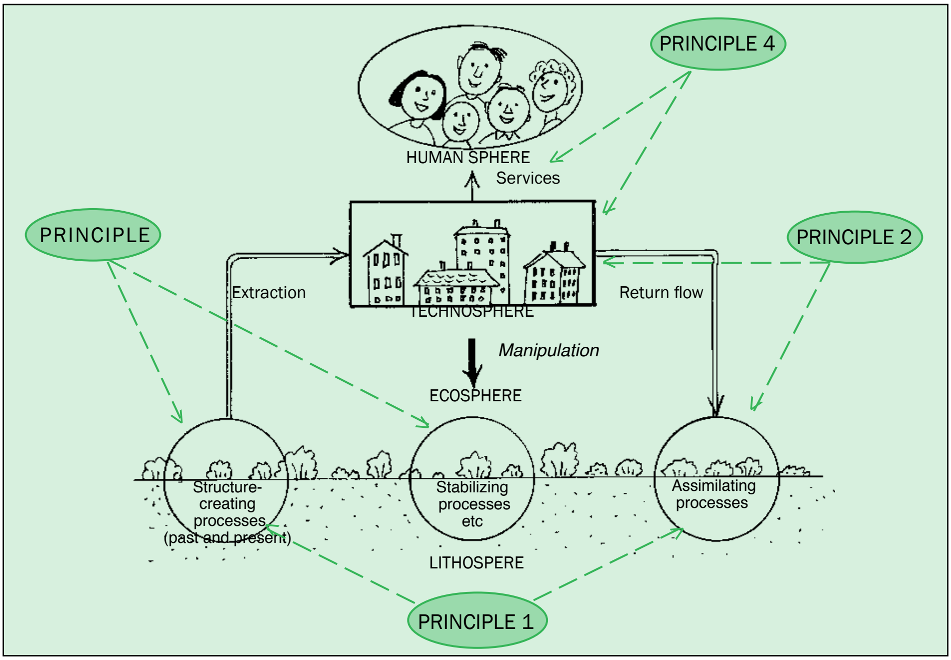


Figure 10.2 The foci of the socio-ecological principles. (Source: Holmberg et al. [1994].)

fossil fuels. Society has more than doubled the flows of SO_2 in the ecosphere. The uranium that is used by the nuclear industry causes risks and damage connected with mining waste, enrichment waste, use in reactors and the management of spent fuel as waste.

The second principle means that substances must not be produced faster than they can be broken down and integrated into biogeochemical cycles or deposited in final deposits in the lithosphere. Otherwise such substances will accumulate somewhere in the ecosphere and the concentration will increase towards limits (often unknown) at which damage starts to occur.

Fulfilling this principle will lead to decreased intentional and unintentional production of natural substances that can accumulate, such as, the production of nitric oxides in combustion processes. The assimilation capacity of the ecosphere is often smaller for persistent substances foreign to nature (for example, DDT) than for substances that exist in nature, because the ecosphere has never adapted to those new substances. Their persistence implies that, after being used, they accumulate in the ecosphere if they are not destroyed within the technosphere. Thus, continued production of such substances cannot be allowed. In practical terms this means that we have to phase out the use of such compounds completely.

10.3 Principles 3 and 4: Using the earth carefully

Principle 3 implies that society must not systematically reduce the physical conditions for production capacity in the ecosphere or the diversity of the biosphere. Society must neither take more resources from the ecosphere than are regenerated, nor reduce natural productivity or diversity by manipulating natural systems.

Our health and prosperity depend on the capacity of nature to reconcentrate and restructure used materials into resources. Society is dependent on the long-term functions of ecosystems. Even if Principles 1 and 2 are fulfilled, society must be careful in its manipulation of the resources base not to lose the productive capacity to supply food, raw materials and fuel. This dependence will become more obvious when the use of fossil fuels and uranium is reduced (according to Principles 1 and 2).

The principle implies a more efficient and careful use of productive areas in agriculture, forestry and fishing and more careful planning of infrastructure.

There is a close connection between soil and vegetation. The quality of soil is often more fundamental than the production of the vegetation on it since soil is more difficult to restore. Vegetation can often be reintroduced if the production capacity of the soil is not damaged and if the specific species are not extinct. It is usually considerably harder to restore eroded slopes (for example in the Mediterranean region) or salinated soils (for example by the Aral Sea). Society's manipulation of land areas also often affects the supply of fresh water. Manipulation of land can decrease natural refilling. It is therefore important to have a balance between extraction from a water reservoir and its natural refilling.

Besides the requirement of production capacity not being systematically reduced, it is im-portant to preserve the stability of the ecosphere. High biodiversity is, as already mentioned, an important factor in preserving the stabilizing functions of the ecosphere. The term 'biodiversity' can be used to summarize three types of biological variation:

(i) genetic variation within a specific species,
(ii) the number of species within an ecosystem and
(iii) the variation of ecosystems (biotopes) within a geographical area.

Principle 4 means that basic human needs must be met with as small an impact on the ecosphere as possible.

Principles 1, 2 and 3 constitute the external conditions for the sustainable metabolism of society. Assimilation capacity as well as the available resources flows are limited. In order to fulfil human needs for a growing global population, the resources and services obtained from nature must be used efficiently within society. Socially, efficiency means that resources should be used where they are needed most. This leads to the requirement of a just dis-tribution of resources among human societies and human beings, within the present generation and between the present generation and future generations.

To achieve this we shall need to increase technical and organizational efficiency in the global society and introduce a more equitable resource distribution including more resource-efficient life-styles in the rich part of the world.

10.4 Adapting materials flows

The flows of materials associated with industrialized society are necessary components in the process of creating services for people. Today, these flows are too large and involve too many harmful substances if there is to be development towards sustainability. The total impact of these flows on nature reflects the unsustainable use of materials today and is seen, for example, in increased global warming, depletion of the ozone layer, increasing metal concentration in soil, rapidly decreasing rain forest areas and destruction of land in connection with mining. How can we decrease the environmental impact of materials use at the same time as maintaining the services that are provided by the flows and transformation of materials?

The box below explains how the ’sustainability equation’ expresses the impact on nature as a product of four anthropogenic factors, that is, four factors that to some extent can be controlled by society. This equation can be used as a starting-point when discussing ways for approaching sustainable materials flows. The factor representing world population, P, is more or less given during the next fifty years. Even an immediate reduction in the birth rate to the reproduction level around two children per family, will, due to the inherent growth momentum in today’s population, lead to around 9 billion people in the middle of the century. Around 10 billion people in 2050 is a central projection in United Nations global population estimates. Population growth may lead to large-scale migration or expectations about sharing resources through, for example, increased exports of food.

If we assume as one goal for development that the use of resources within society must be efficient and just in order to meet human needs, we get a lower limit for the factor that represents the utility per capita (u). Today there are large differences in utility per capita between different countries and between peoples within the same country.

Even if it could be argued that we in the developed countries are (materially) wealthy enough, there are strong demands to increase the average global level of

The 'sustainability equation'

The impact on nature is given as a product of four anthropogenic factors.

Given the population and development goals in the form of global industrialisation, the means to decrease the impact on nature to a sustainable level are dematerialization and transmaterialization of the societal exchange of materials with nature. (There have been various combinations of factors used in this type of equation which goes back (at least) to the seventies.)

The impact **I** is a vector in which each component quantifies a certain kind of environmental impact, for example, radiative forcing, that is, an energy imbalance leading to a climate change. On the right-hand side, this impact is decomposed into the four 'factors'. (Bold style indicates a vector and underlined bold indicates a matrix.):

- the matrix $\underline{\mathbf{I}}$ with components reflecting impact per unit of materials and energy flow,
  $\underline{\mathbf{I}} = \frac{\text{impact}}{\text{material \& energy flow}}$
- the vector **m** describing the size of different flows per service unit,
  $\mathbf{m} = \frac{\text{material \& energy flow}}{\text{utility or service}}$
- the utility per capita u, and
  $u = \frac{\text{utility or service}}{\text{capita}}$
- the global population level P
  P = population

Impact on Nature: $\mathbf{I} = \underline{\mathbf{I}} \times \mathbf{m} \times u \times P$

Corresponding change or state:	transmaterialization	dematerialization	wealthy society	10^{10}
	Mean	*Mean*	*Goal*	*Given*

SUSTAINABLE DEVELOPMENT

service or utility per capita, to reach a higher standard of living in the developing world.

Besides the goal of increasing utility per capita within the present generation, there is also the goal of making it possible to have a high level of utility per capita in the future – the per capita goal is a question of both intra- and inter-generational justice.

The limitations of lithospheric resources put physical restrictions on the possibility of using different materials in the future, for example, the accumulated use of lead in Sweden since 1880 has been about 300 kg/capita. If we compare this figure with what is left in global reserves, namely, 10 kg/capita and the maximum estimate of global resources that can be used in future, namely, 250 kg/capita, it is clear that the Swedish way of using lead over the last century cannot be realized on a global scale in the future.

Further industrialisation of the world and an increasing standard of living, measured as increased economic activity and production of service per capita, as well as the expected increase in the global population to around 10 billion people will thus lead to an enhanced demand for services from material flows.

The simple equation illustrates the dilemma facing humankind – the double challenge inherent in the concept of sustainable development: on the one hand, to develop and reach an acceptable service level from materials/energy flows for a growing population while, on the other, being able to decrease society's harmful physical influence on nature.

10.5 The solutions – reducing the flow or closing the flow

One solution to this dilemma is to be found in the last two factors in the equation, m and i. Concerning world-wide societal flows of materials, one can identify two main strategies for decreasing the environmental impact of materials flows, corresponding to changes in these two factors: dematerialization, that is, more service out of a certain exchange of materials with nature, and transmaterialization, that is, substitution of materials flows with less harmful impact for more detrimental ones.

Dematerialization can be accomplished in two principal ways: less materials flow to achieve a certain service (reducing the flow) or increased recycling of materials (closing the flow), see Fig. 10.3.

Reducing the flow implies more efficient use of a given material for a given function. Copper wire in power transmission is one example of de-materialization. By raising the transmission voltage it has been possible to reduce the amount of copper needed to transmit a given amount of electricity. An even more dramatic improvement is achieved by exchanging the copper cable for an optical cable. Another example is the large reduction of the silver content in a roll of film. To finally end the use of silver all together one may substitute the film for a digital picture.

By increasing the quality of a material, such as the strength of a metal, materials requirements can be reduced. It has been estimated that the Eiffel tower

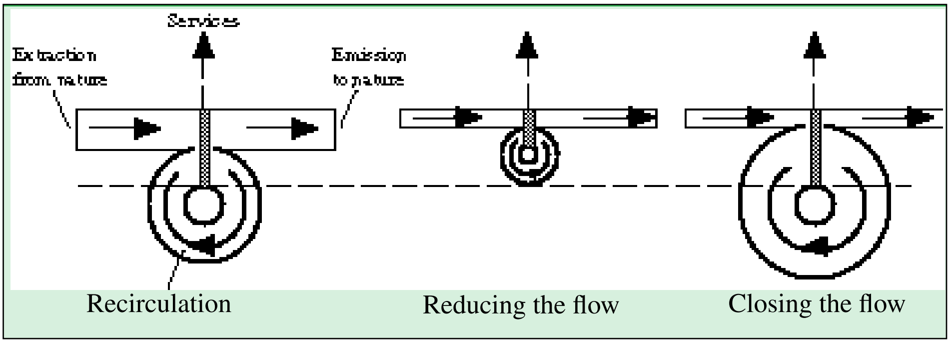


Figure 10.3 Dematerialization can be accomplished in two principal ways: less materials flow to achieve a certain service (reducing the flow) or increased recycling of materials (closing the flow) (Source: Holmberg et al in A Sustainable Baltic Region, Book 3 by Sten Karlsson,BUP Press 1997)

in Paris today could be built with one seventh of the steel content. This possible reduction in iron use is, however, partly achieved by alloying the iron with small amounts of other elements. In the electronics industry we can see an ongoing miniaturization of electronic components as with silicon chips, which can reduce the need for a given material for a given function.

Multifunctional 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.

By making the products last longer the same amount of materials can provide services for longer and therefore the amount of materials for a given service can be reduced. This can be achieved in many ways. For example, we can increase the quality of the materials or components involved. Materials can be protected from wear or corrosion. Repairability, for example through a modular construction, may be possible to increase.

10.6 Recycling

Closing the flow of materials within society implies that the same asset or material is used again and again. Cycles can be closed at various levels. We can reuse goods; for example, glass bottles for packaging can be refilled. Materials in goods can be recycled as with, for example, the metal in aluminium cans or the lead in lead-acid batteries. The closure can be within production processes, where manufacturing waste is fed back into earlier material-processing steps.

In some cases this is already well developed for waste generated early in the production chain, as with copper scrap in the manufacturing of copper wires. However the challenge is to close material flows for complex consumer products. For many materials (for example, toxic and/or scarce materials) it is important that dissipative use, that is use that leads to unavoidable losses of materials is avoided. But, of course, depending on the process, the dissipation is more or less inherent and thus more or less difficult to avoid without more radical changes: For instance, the by-flow of lead additives in petrol may be relatively easily substituted, but it is harder to avoid the dissipation of the petrol itself when used as a fuel.

The quality aspects of recycled material are very important. An important condition for the successful recycling of materials is that flows are sufficiently pure or separable. Unnecessary mixing of different kinds of materials can destroy this and should therefore be avoided. The effects of the inevitable loss of quality in materials can be minimized through a cascading use, where each step involves a drop in quality requirements, so-called downcycling. After each recycling step of a certain material, it should be used in such a way that the quality can be kept at the highest possible level.

One challenge is to achieve a high proportion of true recycling that is recycling of the material to the same use once again. There are three main qualities that are interesting:

- purity,
- structure and
- exergy.

For instance a special steel should not be used as reinforcing iron after only one cycle if the purity is to be saved. The bulk structure of wood, for example, can be utilized, if wood is first used as a construction material, before its fibre structure is used in paper of stepwise declining quality and then its chemical structure is finally utilized in the chemical industry or for fuel production and combustion.

In the energy sector, one can also improve exergy efficiency through cascading use of energy, where each step involves a drop in temperature. In this context Ayres & Ayres [1995] have discussed waste mining as a strategy which utilizes waste streams from (currently) irreplaceable resources, for example, recovering elemental sulphur from natural gas and petroleum refineries. This strategy reduces

1) environmental damage due to the primary waste stream,
2) the rate of exhaustion of the second resource and
3) environmental damage due to mining the second resource.

10.7 Transmaterialization

Even if the use of a certain material is efficient in terms of delivered service per mass unit of the material, the impact on nature may still be unacceptable. In that case, transmaterialization may remove a more serious impact by a shift to a materials use that implies less environmental impact. Transmaterilization can be achieved by, for example, substituting less harmful and/or less scarce materials for hazardous and/or more scarce materials.

Substitution can be done at different technical levels in the system that delivers the services in question; see Table 10.1. The first two levels deal with society's choice of material resources. Levels three and four are connected with the choice of technology, levels five and six deal with organization and strategies and level seven is connected with the type of services we demand.

The amount and the type of services that we demand in the end have consequences for the use of resources. The use of services varies a lot despite the fact

Box 9.2
Materials management strategies.
15 approaches to efficient materials management

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 cop¬per 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 a 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 has 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-mount¬ed solar collector can also function as roofing.

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

5. Improve the quality to make the equip¬ment last longer
By making products last longer, for example by increased quality, the same amount of materi-als can provide services for longer and therefore the amount of materials for a given service can be reduced.

6. Protect the material in the equipment better
Materials can be protected from wear or cor¬rosion. Modern cars last much longer than earlier ones because of better protection of the surface.

7. Better maintenance
By regular maintenance and by using equip¬ment 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 the modular construction of equipment, will increase the longevity of the materials used.

Box 9.2
Materials management strategies.
15 approaches to efficient materials management

III. Closing the flow – use the material again

9. Reuse the goods itself
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 mate¬rial intensity. This is part of waste management strategies. Thus manufacturing waste can be fed back into earlier material-processing steps, as when for example copper scrap in the manu-facturing 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 qual¬ity in material when it is used. However it may be apt for a different use requiring less quality. This is down-cycling or cascading. The typical exam¬ple is paper where the fibres in the paper itself go through a wearing process, which limits the use to a few cycles. The chain might start with high-quality paper going to newspaper and then 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 material for a less harmful one
Transmaterilization means that one material is exchanged for another. An important aspect is when a hazardous material is exchanged for a less harmful one. The exchange of mercury in a number of applications, from barometers to teeth repair, belongs to this category as does the exchange of many solvents used for painting.

14. Substitute a scarce material for a less scarce one
Sometimes it is important to find a less scarce material for a particular use. Substituting cop-per wires in telephone connections by fiberoptic cables is one example.

15. Substitute a non-renewable material for a renewable one
Non-renewable materials will eventually nec¬essarily be exchanged for renewable ones. An important example is when fossil fuels are ex¬changed for renewable fuels, such as biomass. An important case is the exchange of petrol in cars for alcohol from biomass.

that fundamental human needs are the same in all cultures and in all periods of history. Max-Neef [1986] considers those needs to be few and classifiable.

He suggests the following classification: permanence (or subsistence), protection, affection, understanding, participation, leisure, creation, identity (or meaning) and freedom. What changes, both over time and between cultures, is not the needs but the forms or the means by which these needs are satisfied. Since many of the fundamental human needs are not directly associated with any large turnover of natural resources, a plausible conclusion is that society can increase the fulfilment of those needs at the same time as it decreases its use of natural resources.

10.8 Managing future materials flows

Huge movements of materials are induced by the ongoing activities in modern societies. However, as pointed out earlier, materials are not used in themselves but contribute to providing a service. The services delivered, for example measured as the net or gross domestic product (NDP or GDP), have increased dramatically during the industrial era because of economic development, sustained by capital accumulation, technical development and increased skills. This has been followed by an increase in the total use and movements of materials.

Technological development has also made it possible to get more service out of less materials. The mean value added to materials in the production system has successively increased. But at the same time new and more efficient methods have also meant that many materials have become cheaper. Materials use intensity showed a general tendency to increase at the beginning of industrialization but then to level out and decrease. This is especially true for some of the 'old' high-volume materials in society such as iron, cement and lead.

But part of the explanation is transmaterialization: substitution with 'new' materials has contributed to the decrease in intensity of the use of old materials. For new materials, like aluminium and plastics, which have come into common use during the last fifty years, there is still an increasing tendency in materials use intensity. Today in some countries, for example, the use of plastics by volume is larger than all metals together. In the manufacturing of goods, plastics to a large extent have substituted for various metals.

Huge material flows are connected with accumulation of infrastructure, the use of fossil fuels and the linear flows of metals. Halting these tendencies, stopping the expansion of the infrastructure, phasing out fossil fuels and efficient recycling of metals will create a dramatic change and a reduction in materials flows and the rucksacks.

But this will not solve all problems. There will still in society be flows of hazardous materials which will require careful transmaterialization to less harmful alternatives. The pressure on biomass resources will increase and with it the necessity to have more stringent handling of important nutrients. New technologies or other solutions may solve the environmental and resources problems connected with certain materials flows but also, in parallel, introduce demands for new materials, possibly giving rise to new problems. It is thus important to substitute in a direction leading towards an overall more sustainable materials flow.

To be able to achieve the necessary radical decrease in the long-term environmental impact and resources exhaustion resulting from the present practice of materials use, we shall certainly need more control over societal materials flows.

To which extent the means to implement such a strategy can rely on tendencies, mechanisms and institutions already present in society or imply new more radical measures is another question. But probably these means have to differ between various materials or group of materials. The characteristics of materials, the amounts mobilized and their role and through-flow in society as well as their turnover in nature vary considerably, depending on which materials we are focusing on. In Box 10.2 we have tried to summarize some important characteristics for major groups of materials used in society. We have also depicted some possibly important components or central solutions necessary for adoption in materials management strategies aiming towards sustainability.

The production and use of various goods and services will be subordinated to this strategy. We shall thus need a careful mixture of dematerialization and trans-materialization measures to get rid of or decrease what we do not want to rely on and to handle in an acceptable way what we decide to keep. On the way, however, there will be many conflicting goals and choices to be made between different means of achieving more sustainable practices. Questions to resolve may be, for example:

- within agriculture, will more intensive use on limited areas with more control or more extensive use (closer to natural) over larger areas, be the better practice?
- for metals, how can the choice be made between dematerialization and transmaterialization depending on the metal, available technology and the characteristics of the various uses?
- for energy and transportation technologies, to what extent will resources restrictions hinder efficiency improvements and the phasing out of fossil fuels?
- to what extent is it possible to make use of overburden, slag and other rucksacks in the infrastructure instead of discarding them?

Chapter 10 sources:

Baltic University publication A Sustainable Baltic Region, Book 3 by Sten Karlsson Chapter 4 Man and materials flows – Towards sustainable materials management http://www.balticuniv.uu.se/index.php/boll-online-library/819-a-sustainable-baltic-region

Chapter 11
Reducing the resource flows by a factor of 4, 5 or 10

11.1 Concern for mounting global resource flows - Factor Four

When in the beginning of the 1990s it was clear that the global resource flow had become far larger than planet Earth could sustain discussion on how to reduce it became serious. At the Wuppertal Institute in Germany its Director Ernst Ulrich von Weizsäcker together with American colleagues Amory and Hunter Lovins published the ground-breaking book Factor Four – Doubling Wealth, Halving Resource Use. The proposal in the book was that by being four times as efficient in resource use we, that is the world population, could half its resource use without losing any welfare. The authors write in the introduction:

"Factor Four, in a nutshell, means that resource productivity can - and should - grow fourfold. The amount of wealth extracted from one unit of natural resources can quadruple. That message is novel, simple and exciting.

It is novel because heralds nothing less than a new direction for technological progress. In the past progress was the increase of labour productivity.

We feel that resource productivity is equally important and should actually be pursued with highest priority.

Our message is simple by offering a primitive quantitative formula. Our book depicts technologies representing a quadrupling or more of resource productivity. Progress must, as we know since the Earth Summit of Rio de Janeiro, meet the criterion of sustainability. Factor Four progress does.

The message is also exciting. It says that some of that efficiency revolution is available now at negative cost, i.e. profitably. Much more can be made profitable. Countries engaging themselves in the efficiency revolution become stronger, not weaker in their international competitiveness.

That is not only true for the old industrialized countries. It is even more valid for China, India, Mexico or Egypt which have a supply of inexpensive labour but are short of energy. Why should they learn from the US and Europe how to waste energy and materials? Their development to prosperity will go smoother, swifter and safer if they make the efficiency revolution the centrepiece of their technological progress.

The efficiency revolution is bound to become a world trend. Who wants to be the early leader and rip the benefits of the pioneer?"

Later on they go in some detail and write:

"Most of the energy, water, and transportation services we consume are wasted too, often before we get them: we pay for them, yet they provide no useful service. The heat that leaks through the attics of poorly insulated homes; the energy from a nuclear or coal-fired power station, only 3% of which is converted into light in an incandescent lamp (70% of the original fuel energy is wasted before it gets to the lamp, which in turn converts only 10% of the electricity into light); the 80–85% of the gasoline used in a car wasted in the engine and drivetrain before it gets to the wheels; the water that evaporates or dribbles away before it gets to the roots of a crop; the senseless movement of goods over huge distances for a result equally well achieved more locally - these are all costs without benefits.

This waste is unnecessarily expensive. The average American, for example, pays nearly $2,000 a year for energy, either directly purchased for the household or embodied in businesses' goods and services. Add in wasted metal, soil, water, wood, fibre, and the cost of moving all these materials around, and the average American is wasting thousands of dollars every year. That waste, times a quarter-billion people, yields at least a trillion dollars per year that is needlessly spent. Worldwide, it may even approach $10 trillion, every year. Such waste impoverishes families (especially those with lower incomes), reduces competitiveness, imperils our resource base, poisons water, air, soil, and people, and suppresses employment and economic vitality.

Yet the wasting disease is curable. The cure comes from the laboratories, workbenches, and production lines of skilled scientists and technologists, from the policies and designs of city planners and architects, from the ingenuity of engineers, chemists, and farmers, and from the intelligence of every person. It is based on sound science, good economics, and common sense. The cure is using resources efficiently: doing more with less. It is not a question of going backward or "returning" to prior means. It is the beginning of a new industrial revolution in which we shall achieve dramatic, increases in the resource productivity.

Ways to do this have significantly expanded in the past few years, opening up wholly unexpected opportunities for business and society. This book is an introduction, description, and call to action on behalf of those opportunities in advanced resource efficiency. It shows practical, often profitable ways to use resources at least four times as efficiently as we do now. Or to put it another way, it *means we can accomplish everything we do today as well as now, or better, with only one-fourth the energy and materials we presently use. This would make it possible, for example, to double the global standard of living while cutting resource use in half.*

Further improvements on an even more ambitious scale are also rapidly becoming feasible and cost-effective.

Doing more with less is not the same as doing less, doing worse, or doing without. Efficiency does not mean curtailment, discomfort, or privation. When several Presidents of the United States proclaimed that "energy conservation means being hotter in the summer and colder in the winter," they were not talking about energy efficiency, which should make us more comfortable by improving the building so that it provides better comfort while using less energy and less money. To avoid that common confusion, this book avoids the ambiguous term "resource conservation" and instead uses "resource efficiency" or "resource productivity."

11.2 Revolutionizing energy productivity

The Factor Four book has a long series of example how to improve resource productivity. Here is from Chapter 1 on energy.

"In earlier days people called it energy savings. This term had a moralistic connotation. Father would admonish his children to switch off lights when leaving a room and never to let motors or appliances run when not needed.

When environmental protection entered the scene, the obvious reaction was on the part of the establishment: You (young and demanding folks) can get as much environmental protection as you want if you are prepared radically to reduce your demands. Energy savings was thus very convenient a as notion for the establishment.

Later, a new term came up: the rational use of energy. By using this term you boost your reputation by signalling that you are an expert in energy matters. How could we therefore dare to reject this term. But we are not happy with it either. It sounds so bureaucratic, complicated and defensive. It doesn't convey any pleasures and is not straightforward in talking about technological progress.

Technological progress is where we come in. Our book is about redirecting technological progress. This is why our favourite term is energy productivity.

We actually find it a bit scandalous that the term productivity has been narrowed down by economists to mean only labour productivity. In the past, labour productivity was a nice thing meaning prosperity. Today, the inevitable connotation with labour productivity is the threat of unemployment.

Energy productivity, on the other hand, is something everybody can greet with joy. Virtually nobody is losing by it.

We are talking about a factor of four in increasing energy productivity.

How could that programme be expressed in terms of energy savings or the rational use of energy? How could we when using the older terms convey the sense of joyous attack on our prevalent technological dinosaurs? How could we create excitement with women and men in the engineering professions, in factories, think tanks, parliaments, governments, lobbies, in the US as well as in Japan, China, India, Europe, Brazil or Egypt?

By using factor four as a standard, we appear to exclude much of the manufacturing world. Smelting aluminium from bauxite cannot for reasons lying in the laws of thermodynamics be made four times more energy efficient. The same holds for chlorine, cement, glass and some other basic materials. But we need not give up for that. Aluminium and glass are superbly recyclable which saves a lot of energy. Some can be substituted with no damage to the manufacturing sector. On a life cycle basis a factor of four in energy productivity should be available for most end user services involving metals or glass.

However, in this book we are concentrating on examples with a straightforward potential of quadrupling energy efficiency or more."

The examples which follow include the more efficient car, either by being lighter, or cleverer such as hybrid cars, or being better used. It includes also houses which are better insulated or even the German passive houses. There is a total of twenty examples of how to achieve 4x energy productivity. Some of them are trivial. Thus if two people instead of one is travelling in a car we have achieved a factor of two without losing any welfare. If two families were sharing a tool or other equipment, instead of having one each, we have again achieved a factor of two.

11.3 The Factor 10 and Factor X Institute

Next step was taken by another of the directors of the Wuppertal institute, Prof. Dr. Friedrich Schmidt-Bleek. In his analysis he pointed out that resource use was not at all equally shared between the different countries in the world, and some had to decrease its material flows more than others. He said in his Factor Ten book published in 1993:

1) "The global resource use before the time when large-scale environmental impacts were observed was about ½ of that in the early 90ies;
2) Some 20% of the world population consumed about 80% of the natural material;
3) Equity demands equal access to natural resources by all people.

Presently the yearly global per capita material mobilization amounts to over 15 tons (without considering water and ploughed soil), suggesting that 6-8 yearly tons per capita may well be close to a sustainable consumption limit, including the use of energy carriers. Given the large-scale adjustments necessary, such a target may not be reachable before the middle of the 21st century."

The Factor Ten book is in English called The Fossil Makers. From the introduction I cite:

"The material flows tied up with producing the wealth we have come to enjoy, are, especially for the people of the rich countries, a global phenomenon. It is our conclusion that our present goods, services and infrastructures are too material and energy intensive. This is calculated "from the cradle to the grave," or, as Walter Stahel3 says, "from the cradle to the cradle," as all the materials and energy we use eventually return to the earth. We must create a dematerialized economy, supported by a completely new technology and informed by a concern for the welfare of future generations. In this book we shall also entertain the question of whether or not the demands our economy makes upon surface - or land use - are too high, and how one could possibly measure surface use in an ecologically meaningful way.

If our present economic activity, i.e. the methods by which we generate wealth, stands a chance of ruining what is perceived to be a more or less beneficent environment, any future eco-politics, or "earth-politics," as Ernst Ulrich von Weizsäcker would call it, must concern itself with the creation of an ecologically sustainable economy.

We must dematerialize our western economies by an average factor of ten or more, as well as de-energize them, if they are to be sustainable. This emphasis on the West derives from the fact that in the industrialized North we lay claim to roughly eighty percent of the global anthropogenic material flows to create our material wealth. A more equitable distribution of access to resources would therefore require considerable reductions in the West, if we entertain the hope of merely cutting in half the global environmental burden.

It appears that such a dematerialization would also lead to a drastic reduction in the volume of solid waste, especially if sensible closed-loop options were utilized. Furthermore, entirely new means for limiting the use of toxic substances would emerge. From a technological perspective this is no utopian goal, even if the quality of goods and services remain equivalent. We shall be offering some examples of the "eco-efficiency revolution" in the pages to come."

And later: "In this book we attempt to get at the root causes of environmental changes, rather than trying to trim some of the branches. We believe this root to be the material flows which we set in motion - even those which permit us to use energy. To make this plausible, to draw some preliminary conclusions and to discuss these conclusions is the concern of this book."

11.4 Why Factor Ten?

Professor Friedrich Schmidt-Bleek writes about how the concept of Factor Ten originated during a discussion with some Russian colleagues. The question was how to avoid ever-increasing costs for protecting the environment. Or if there was perhaps even a way to reward increasing protection efforts within the "real" economy through market forces while simultaneously decreasing the resource use:

"The "Gedankenblitz" (the illuminating thought) occurred to me at a silent location: If too much environmentally dangerous material escapes at the back-end of an economy, one should curb the input streams of natural resources at the front end of the wealth machine. Of course some questions had had to be answered before this simplistic idea could be taken seriously. The first one is: Could technology provide goods and services that offer undiminished end-use satisfaction with substantially less natural resources?

The answer is yes, in principle. It is a question of engineering intelligence how much and what kind of energy and mass one invests for generating a certain quantity of value or utility. Today, some 35 kg of non-renewable nature are used on the average to produce 1 kg of product, and many times this quantity is used in the form of water. Moreover, the stuff we call high tech consumes at least ten times more solid nature than the average technology today. A service oriented knowledge society, supported by (dematerialized) information technology, can go a long way to replace mass and energy by brain power. In fact, how else can growth be had on a planet with limited resources in the face of a growing population with increasing demands?

So far so good, I thought. But then the question arose, what is the required reduction in using nature as input into the worldwide economy in order to approach sustainability? I did a very simple computation based on available evidence and arrived at about a Factor 2 as the best possible estimate. Nobody has as yet contested this rough number to my knowledge.

But surely the poor of this world, some 80% of its population, were not ready to reduce the little they had access to. They dream of proper health care, shelter, *washing machines and cars – not the least because we beam these dreams into their huts incessantly by satellite. We call this stimulating consumption in order to keep the throughput economy running. So if the worldwide take of nature must be reduced by a Factor 2 and equity demands that 5 or 8 billion people must have a better life than now, the rich must reduce their current take at least by a Factor 10. In my opinion, anybody suggesting less than10 should clarify the underlying.*

When I first published the Factor 10, people called me a fool. In particular engineers thought such acrobatics in numbers were far away from real life - until they discovered that I was not talking about 1000 % improvements in efficiency of existing technology, but rather meant the sharp reduction in use of nature for satisfying defined needs of people. The focus of my concept is on service or utility, not goods. As Aristotle remarked already more than two thousand years ago: "True wealth is the use of things, not their possession".

I said above that a future service oriented knowledge society should be capable of dematerializing the economy. But what about reality? Is Factor 10 a pipe dream or not?

There is now a wealth of published examples that demonstrates that Factor 10 and much more can be achieved without reducing end use satisfaction.

In 1993 we started at the Wuppertal Institute in Germany to get involved in practical approaches of dematerialization. Starting in 1997 my newly created Factor 10 Institute in the Provence continued practical work in Europe and Japan, and since 1998 the International Factor 10 Innovation Network has shown in more than 100 enterprises how systematic new design and sensible management approaches can profitably increase the resource productivity of goods and services. When designing products for improved resource productivity, the resource intensity of raw material plays an important role. For instance, we figured out that 1 kg of copper requires 500 kg of non-renewable nature before it is available for constructing something. The ratio for aluminium is 85, for paper 15, for steel around 10 and for most plastics considerably less than 10. Depending on its composition, a product can thus have a much larger - or smaller - "ecological rucksack" than its competitor and still weigh the same.

While painstakingly working through dozens and dozens of supply chains in order to evaluate the rucksack ratios for raw materials we discovered that it is the rucksack of finished products rather than the process of manufacturing that determines the overall resource intensity of the economy: Sustainability is won on the market or not at all."

11.5 Factor 5 and the Kondratiev cycles

In an update to the 1997 international best seller Factor Four Ernst von Weizsäcker again led a team to present a compelling case for sector wide advances that can deliver significant resource productivity improvements over the coming century. The purpose of this book is to inspire hope and to then inform meaningful action in the coming decades to respond to the greatest challenge our species has ever faced – that of living in harmony with our planet and its other inhabitants.

This 2009 book, called Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity, is a more detailed work on how to achieve the 80 % in reduction of resource use. The author team relies on technological development as analysed in the Natural Edge Project, of which they are all members. From the Introduction I cite:

"In the first case, the focus of this book, we would see our sophisticated understanding in areas such as physics, chemistry, engineering, biology, planning, commerce, business and governance accumulated over the last 1,000 years brought to bear on the challenge of dramatically reducing our pressure on the environment. The second case however is the opposite scenario, involving the decline of the planet's ecosystems until they reach thresholds where recovery is not possible, and following which we have no idea what happens. For instance, if we fail to respond to Sir Nicolas Stern's call to meet appropriate stabilization trajectories for greenhouse gas emissions, and we allow the average temperature of our planet's surface to increase by 4-6 degrees Celsius, we will see staggering changes to our environment, including rapidly rising sea level, withering crops, diminishing water reserves, drought, cyclones, floods… allowing this to happen will be the failure of our species, and those that survive will have a deadly legacy.

The purpose of this book is to inspire hope. It is not good enough simply to present a highly theoretical picture of how technology could save the world. Instead we want to present practical pictures of whole systems of technologies, infrastructures, legal rules, education and cultural habits interacting to produce economic progress while conserving a healthy environment. Virtually all the strategies outlined in this book can be applied now by nations, companies and households to achieve Factor Five. This 'whole system approach' will also help overcome the rebound effect of additional consumption gobbling up all technological efficiency gains that were meant to save resources and conserve the environment.

To fill this message with real world substance, we present numerous examples of resource productivity improvements from the most relevant sectors, showing *that the said Factor Five, or 80 per cent, reduction of environmental impacts per unit of economic output, is available. This multifaceted universe of opportunities represents the core body of our book."*

And later: "During a time of recession, commentators often speak about, and hope for, the 'next upswing'. Usually it is the short kind of business cycles people have in their minds. But there are also long-term cycles, every 30–50 years, which can be attributed to major technological innovations. Although standard economic literature does not necessarily accept the idea of long-term cycles, they have been a useful way of describing, characterizing and perhaps even explaining historical periods that are associated with technology-driven major economic upswings. The best-known early scholar to describe such long-term cycles was the great Russian economist Nikolai D. Kontratiev (1892–1938). His pivotal book was called The Major Economic Cycles and was published in 1925.

Kondratiev himself had no strong emphasis on technological change, but Joseph Schumpeter, the famous Austrian and later American economist, saw business cycles and long-term cycles as associated with major technological innovations. It was Schumpeter himself who suggested honouring Kondratiev (killed in 1938 by Stalin's 'Purge' firing squads), by calling the long cycles 'Kondratiev Cycles'. Paulo Rodriguez Pereira gives a crisp account of the long cycle discussion, with some emphasis on what it means for developing countries. Referring to Joseph Schumpeter, Christopher Freeman and Carlota Perez, Pereira says that Kondratiev cycles are not an exclusive economic phenomenon but result from a reorientation of industrial organization and management, based on 'technologies that underlie the existing economic cycle. Kondratiev cycles are thus associated with major technical changes'. From this observation, he also derives the need for developing countries to strengthen their technological capacities.

In line with such a 'Schumpeter–Freeman–Perez' paradigm of waves, Pereira describes the five familiar historical cycles as:

1. The early mechanization cycle since the 1770s;
2. The steam power and railway cycle since the 1830s;
3. The electrical and heavy engineering cycle since the 1880s;
4. The Fordist and mass production cycle since the 1930s (although he could have given an earlier start for that one);
5. The information and communication cycle since the 1980s (he could have added biotechnology to the description).

Our point is that, according to historical evidence since Kondratiev's pivotal work, the magic of technological innovations tends to fade after some 20 to 30 years of its beginning. So it may not be too surprising that even the most exciting recent wave of innovations in information technology, biotechnologies and, somewhat more recently, nanotechnologies, is no longer strong enough to support worldwide economic growth.

Fading excitement with certain technologies would not yet make for a massive – and sudden – economic downturn. The arrogance and failures of much of the financial sector was the obvious cause of the present crisis. But if we want the economy to gain strength again, an exciting new wave of technologies might be the biggest hope for the world. A couple of years before the present crisis, Paul Hawken, Amory Lovins and Hunter Lovins, in Natural Capitalism, also summarizing the theory of long-term cycles, came up with the suggestion of a new industrial revolution unfolding, with energy and resource efficiency at its core.

Building on from this pivotal work, Charlie Hargroves and Michael Smith from The Natural Edge Project, and co-authors of this book, suggested in their 2005 book, The Natural Advantage of Nations, that the emerging wave of green technologies could be seen as the beginning of a new Kondratiev Cycle, as shown in Figure 11.1, and noting that the time frame for such waves is quickening.

As we have observed before, some greening of technologies and the economy is already under way. We do suggest that the process of greening, being the logical answer to the environmental constraints, will generate the new and reliable sense of direction that could pull us out of the recession. For this to happen, some additional momentum will be highly desirable. If the conviction spreads that the greening trend is inevitable and can take the shape of a full-size Kondratiev Cycle, we are confident that the desired momentum will come. Investors then have clarity about where to put their bets.

Reflecting on the ingredients for a big new cycle, we seem to discover three that can be identified in each of the earlier Kondratiev cycles.

1. One ingredient, as we said, seems to be the loss of magnetism of the technologies that characterized the former cycle. Such was the case with the railroads around 1900. The discoveries and innovations of electricity, the internal combustion engine and chemical technologies created a lot more excitement at the time than a further expansion of the railway network would have done. Thomas Edison, Gottlieb Daimler and Henry Ford, and European chemical innovators and entrepreneurs became the heroes of a new wave of growth and innovation. The next wave, characterized by petrochemicals, aviation and early electronics, was generated almost entirely in the US – but later also fertilized the Old World,

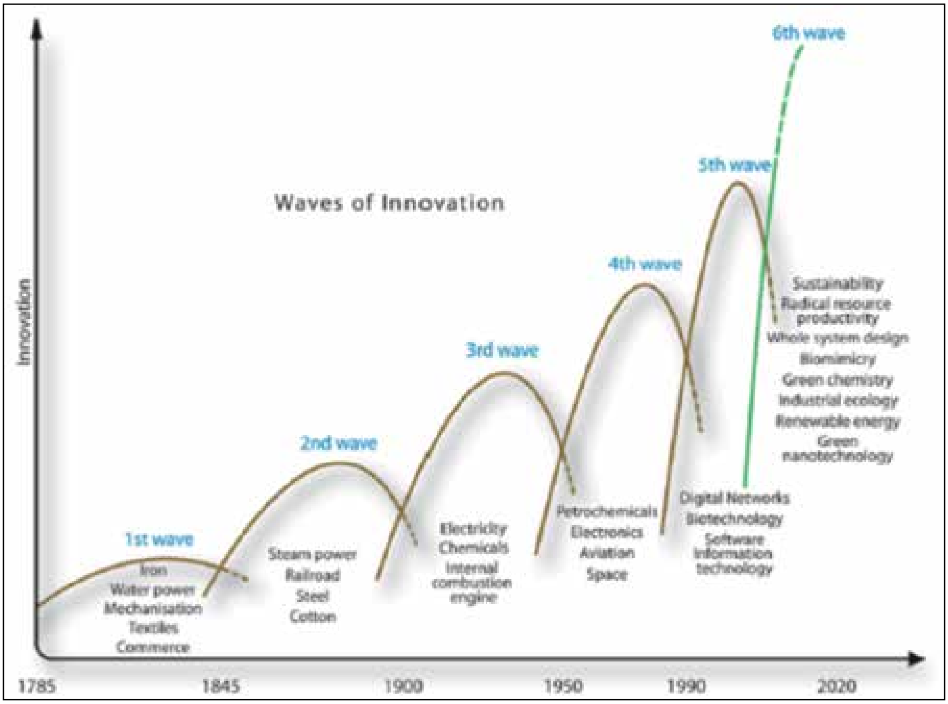


Figure 11.1 Waves of innovation (Source: Courtesy of The Natural Edge Project)

including the Soviet Union. It was triggered, in part, by the fading excitement with classical electrical and chemical engineering.

2. Another ingredient for a new wave is strong demand for new products and services. It should be noted, however, that much of the demand may be sleeping in the early phase of the new wave. Perhaps the best example for that has been information technology. Mainframe computers did not look like they would be useful to everybody. Electric typewriters, copiers and printers were widely used but did not spell excitement. TVs became widespread as well, but nobody associated them with computer screens or data processing. The miniaturization of electronics to save weight for spaceships and aeroplanes remained an 'outlandish' affair. However, when computers, typewriters, TV screens and miniature electronics merged into the desktop computer technology, a whole new universe of applications and demand was awakened. Endless waves of software development, breath-taking advances in further miniaturization and finally the development of the Internet and of search machines made IT a seemingly non-ending success story, constantly creating its own additional demand.

Also, earlier technological waves met with moderate demand at the beginning, but more demand germinated and blossomed as supplies got ever more affordable. This was surely the case for textiles, railroads, strong machinery, automobiles, chemical plastics, fertilizers and machinery for the farm, pharmaceuticals and diagnostics, electric appliances, air travel and industrial robots. And mass manufacture, explicitly mentioned by Rodriguez Pereira for the fourth Kondratiev cycle, clearly made goods more affordable and thereby stimulated demand that was unimaginable at the beginning of the cycle.

3. The third ingredient for a new big wave is perhaps the most visible: the invention and development of exciting new technologies – the steam engine, the internal combustion engine, chemical plastics, aircraft, the TV, uranium fission, penicillin, the laser, home computers, and centralized data storage and search engines – were all celebrated as scientific inventions or technological breakthroughs. But hundreds of other inventions were also made without having big economic impacts.

11.6 A Sixth wave of innovation

The Factor Five authors suggest that much of the dynamics leading to a Kondratiev cycle comes from a combination of the three major ingredients:

- fading excitement with old technologies,
- rising demand for and affordable supplies of the new goods and services, and indeed
- some exciting new technologies.

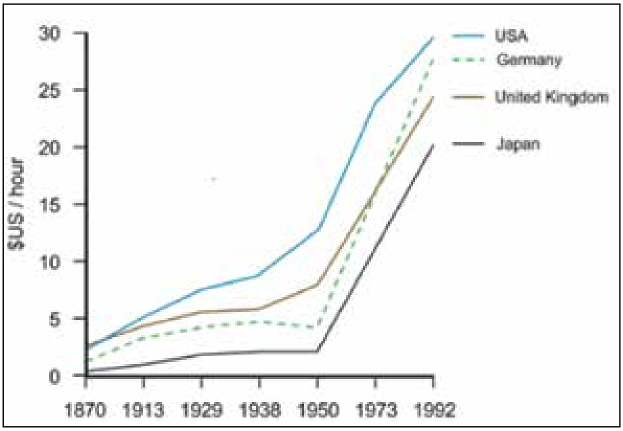


Figure 11.2 The development of labour productivity over 120 years (Source: Courtesy of Raimund Bleischwitz)

“At any rate, we feel that all three ingredients are there for the launching of a very major new wave of innovation, the Green Kondratiev cycle, or the 6th Wave of Innovation.

In this case we suggest that the strongest pull factor is demand. A world population almost twice the size of the time of the last big cycle wants food, shelter and huge amounts of additional goods and services, and all under conditions of decreasing or stagnating supplies of energy, water, land and minerals. The greenhouse effect greatly exacerbates the problem by further reducing energy and farming options. Some fatigue can be observed also with the old technologies, notably in as much as they are seen as destructive to the environment. Even IT and biotechnology are experiencing some signs of saturation. IBM, one of the most successful companies in the modern high-tech world, sold their computer manufacturing to China. And Silicon Valley in California, the cradle of the IT revolution, is shifting its attention to green technologies.

Biotechnology companies try to prove their usefulness by offering drought resistant crops or energy-saving microbes for washing and cleaning.

Nanotechnologies came into lots of controversies and legal questions and are in need of proving their usefulness for resource-saving technologies as well.

What is more, and this is the core of our book, is the availability of a wide range of fascinating new technologies promising to be roughly five times more resource efficient than those still dominating industry, households and the service sector. So we do not hesitate to call for and promote a new Green Kondratiev cycle.

Greening the economy is perhaps a popular way of characterizing the innovations we expect to happen in the course of the Green Kondratiev. But we suggest going one philosophical step further. We observe, as economic historians are likely to agree, that the first 200 years of modern age economic development had the ‘increase of labour productivity’ as the one unifying motto. Labour productivity rose at a pace of roughly 1 per cent per year during the 19th century until the middle of the 20th century. From then on, owing to the accelerated global spread of technologies, progress increased by about 2–3 per cent per year. Overall, labour productivity has increased twenty-fold over those last 200 years. Figure 11.2 shows a time window of some 120 years marking the impressive acceleration after World War II.

Today, labour is not in short supply. Otherwise the International Labour Organization (ILO) would not speak of a shortfall of 800 million jobs to create a situation of near full employment. On the other hand, as we have indicated before, energy and other natural resources are in short supply, and the scarcity is getting worse every decade. This situation calls for a reversal of the emphasis on technological progress. Resource productivity should become the main feature of technological progress in our days. Countries making the scarce production factors more productive should enjoy major economic advantages over those ignoring the new scarcities. This is another way of emphasizing the need for a new technological cycle and a new orientation for the world economy, for national economies, and for individual firms.

To relate this to the long cycle considerations, the Green Kondratiev should become the first cycle during which resource productivity grows faster than labour productivity. In developing countries, the increase of labour productivity will, of course, remain a high priority because they want to catch up with industrialized countries. But they should avoid doing so at the expense of resource productivity. Many studies show that such a focus will help to boost the economy and create jobs, while reducing environmental pressures. As The Natural Edge Project explain in their upcoming publication Cents and Sustainability, investments in resource productivity transform and stimulate the economy in three main ways:

First, investments in resource productivity, such as building energy efficiency, have a higher economic multiplier than general expenditure, as resource efficiency investments provide a tangible financial return on investment as well as usually providing additional productivity improvements.

A recent 2007 study by McKinsey & Company has found that, through investing in energy efficiency, global emissions could be reduced by 20–30 per cent by 2020 without harming business profitability or economic growth at all. Thus once the return on investment is achieved, usually within 1–2 years, business, government departments and households have lower annual costs and thus more money to spend elsewhere. If they then choose to invest this money in additional cost-effective resource efficiency opportunities, still more funds are generated over time, which can be reinvested, further stimulating economic activity.

Secondly, investments in improving resource efficiency and recycling have a higher economic welfare outcome than general expenditure on many goods and services because they reduce demand for energy, water and virgin resources and thus delay (and even in some cases prevent) the need to spend billions on new energy and water supply infrastructure and new extractive industries. Resource efficiency investments and demand management has been shown to help nations avoid infrastructure investment so that infrastructure funding can be targeted to where it is most needed. This is an important consideration since there are already insufficient funds to spend on all the potential and desirable infrastructure projects. Take the electricity sector in Australia. Experts say if current demand for electricity continues to rise with the current trend, A$30 billion will need to be spent on new electricity supply infrastructure. By contrast, in California, energy efficiency, greener building codes and demand management have led to a flattening over the last 20 years of previously rising electricity demand.

California through its strong climate change policies has achieved significant reductions in electricity consumption per capita compared to the rest of the US – an estimated net saving of US$1000 per family. Sweden, the UK and the Netherlands have all achieved flattening of previously rising electricity demand through policies that encourage energy efficiency.

Thus, tens of billions of dollars can be saved by avoiding unnecessary infrastructure investments, and thus freeing up capital to instead be invested in additional eco-efficiency initiatives, recycling plants and local distributed renewable supply options for energy and water.

Thirdly, jobs are created locally by green initiatives. This results in more of a city's or town's energy, water and materials dollars being spent in a way that supports local jobs and the local economy. Also these new local 'green' jobs have a direct effect of attracting more people to the city or town who then contribute to that local economy. California's energy-efficiency policies created nearly 1.5 million jobs from 1977 to 2007. Germany claims to have 1.2 million green jobs already, and another 500,000 on the drawing board. The UK has announced a target of one million green jobs. US President Obama has promised to create five million green jobs.

In Australia, as mentioned above, the Australian Council of Trade Unions (ACTU) and Australian Conservation Foundation (ACF) says almost one million jobs could be created in the next 20 years if the Federal Government promotes green industries. Their 2008 report showed that, with the right policy settings, six market sectors in the Australian economy (renewable energy, energy efficiency, sustainable water systems, green buildings, biomaterials and recycling and waste), currently valued at US$15.5 billion and employing 112,000 people, could grow to a value of A$ 243 billion and 847,000 jobs by 2030.

11.7 Sectors with 5 times resource productivity increase

In Part one of the Factor Five book a more detailed description how to achieve five times improved resource productivity in different sectors is described. For each sector the different components of improvement are listed and how much percentage each of them contributes to the total of 80%. Below follows some of the proposals (source: Factor Five Sample PowerPoint Slides on Sector Studies: in http://www.naturaledgeproject.net/factor5.aspx)

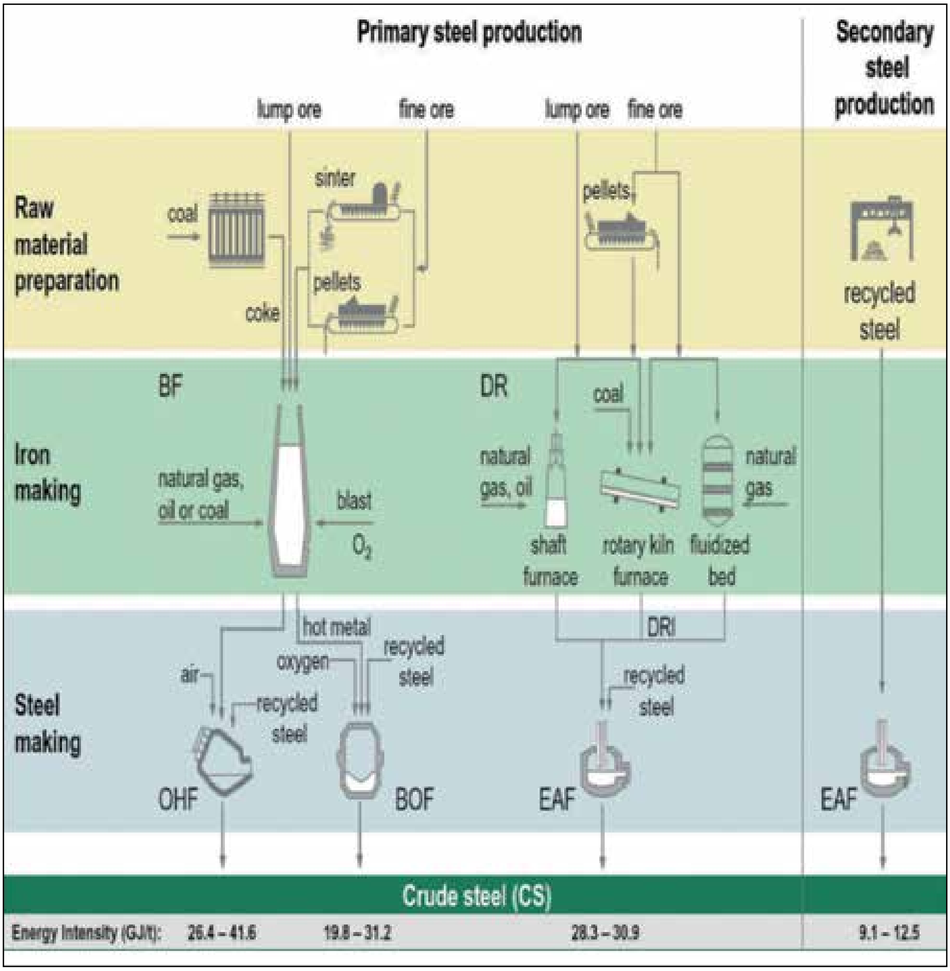


Figure 11.3 Resource efficient steel production (Source: http://www.naturaledgeproject.net/factor5.aspx)

1. Residential Buildings
   Improvements in heating and cooling of the house; More efficient hot water system; Indoor lighting; energy efficient refrigeration and appliances.
2. Commercial Buildings
   Building orientation and envelope; Better Air conditioning; efficient office equipment; retrofitting of existing buildings
3. Heavy Industry (Steel Production)
   EAF production method, Net Shape Casting, Energy recovery, Fuel switching, Preventative maintenance.

Figure 11.4 The Hypercar Revolution. Source: http://www.naturaledgeproject.net/factor5.aspx

4. Heavy Industry (Cement Production)
   Use of Alumina silicate, Improved Materials efficiency, Fuel Switching, Kiln design
5. Agriculture
   Material efficiency, Renewable energy, Fuel Switching, Appropriate selection of crop species, Energy efficiency
6. Transport (Cars & Light Vehicles)
   Light weighting rolling resistance, Aerodynamics, Engine and driveline efficiency, Vehicle-Grid integration, Alternatives to internal combustion engine, ICE; behaviour change; Transit oriented cities
7. Transport (Heavy Freight Vehicles)
   Light weighting rolling resistance; Aerodynamics, Engine and driveline efficiency, Operational improvements, Logistical improvements, Alternative modes of freight transportation

1. Transport (Rail) Light weighting

Figure 11.5. Standard truck and an energy efficient truck, the Eaton/Peterbilt Diesel-Assist Hybrid. Source: http://www.naturaledgeproject.net/factor5.aspx

Engine efficiency, Regenerative breaking, Reduced drag/friction, Improved logistics, Load factor management, Idling energy saving, Energy efficient lighting, Speed optimisation

One may add to this list of possibilities several more. Thus for the housing sector, low energy housing of passive housing reduces energy use in housing very dramatically. In addition wooden houses decreases resource use in the building itself.

Steel industry should use as much as possible recycled scrap metal. It reduces energy need by a factor of about 6. As to the cement industry it should decrease as much as possible since cement production contributes considerably to CO2 emissions.

Agriculture should make efforts of recycling nutrients and use manure and other organic material for biogas production.

It is interesting to see that in the transport sectors the Factor Five authors include elements of organisation and behaviour as important for resource use improvements. Probably this is valid for all sectors although more detailed analysis is needed to specify exactly what should be done.

Chapter 11 sources:

Factor Four - Doubling Wealth, Halving Resource Use; The new report to the Club of Rome by Ernst Ulrich von Weizsäcker; Amory B. Lovins and L.Hunter Lovins

http://www.ima.kth.se/im/3c1395/Pdf/FactorFour.pdf

Factor 10 Institute http://www.factor10-institute.org/

The history of Factor 10 by Friedrich Bio Schmidt-Bleek

http://www.factor10-institute.org/files/MIPS_History.pdf

The Fossil Makers (Wieviel Umwelt braucht der Mensch?) by Friedrich Bio Schmidt-Bleek

http://www.factor10-institute.org/files/the_fossil_makers/FossilMakers_Intro.pdf

The World Resources Forum http://www.wrforum.org/

Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity by Ernst Ulrich von Weizsäcker, Charlie Hargroves, Michael H. Smith Cheryl Desha and Peter Stasinopoulos

http://www.naturaledgeproject.net/factor5.aspx
Factor Five Sample PowerPoint Slides on Sector Studies
http://www.naturaledgeproject.net/factor5.aspx)
The Natural Edge Project (TNEP) is a collaborative partnership for research, education, and policy development on innovation for sustainable development
http://www.naturaledgeproject.net/About.aspx

Chapter 12
Economic growth and decoupling of resource flows

Introduction

The dominating policy in almost all countries, regions and municipalities today is economic growth. Political leaders see economic growth as the one and only way to improve economy and wellbeing, reduce unemployment and, not the least, find more income to public administration by taxation, fees and other benefits from society, needed for all kinds of reforms. Here we shall briefly say that even if economic growth has occurred at least since the 18th century, as a dominating policy it is more recent, from about 1950s. Before that military security and security of the state dominated.

Each economic activity requires some resource flow. This is obvious when it comes to concrete physical projects such as building houses, developing infrastructure etc, but it is also the case for a number of activities in the service sector. You need workplaces, equipment, transport etc for which ever activity you may pursue. In some cases the resource flow may be very large, e.g. in tourism which today is increasing very rapidly.

Economic growth thus challenges us with a dilemma of sustainable development. No kind of growth can go on forever on a finite planet. An answer has been to develop a non-growth economy, or put it more mildly, an economy which may grow only in quality, not quantity. Another way is to make economic growth independent of the resource flow. This is called decoupling. It requires that the so-called resource intensity of the economy is decreasing. Thus decreasing energy intensity means that the economy, measured e.g. in GDP, is increasing while the energy use is constant or decreasing or at least increasing with a lower speed than the economy.

This chapter consists of chapter 4 in the famous book Prosperity without Growth, published as a report from the United Kingdom's Commission and authored by Tim Jackson, who then worked for the Commission (See further the sources for this chapter). It is probably the most downloaded report ever from the UK Commission on Sustainable Development. All references as well as additional figures are found in the original text (See sources).

12.1 Economic growth and resource consumption

The conventional response to the dilemma of growth is to appeal to the concept of ‘decoupling’. Production processes are reconfigured. Goods and services are redesigned.

Economic output becomes progressively less dependent on material throughput. In this way, it is hoped, the economy can continue to grow without breaching ecological limits – or running out of resources.

It’s vital here to distinguish between ‘relative’ and ‘absolute’ decoupling. Relative decoupling refers to a decline in the ecological intensity per unit of economic output. In this situation, resource impacts decline relative to the GDP. But they don’t necessarily decline in absolute terms. Impacts may still increase, but do so at a slower pace than growth in the GDP.

The situation in which resource impacts decline in absolute terms is called ‘absolute decoupling’. Needless to say, this latter situation is essential if economic activity is to remain within ecological limits. In the case of climate change, for instance, absolute reductions in global carbon emissions of 50-85% are required by 2050 in order to meet the IPCC’s 450 ppm stabilisation target.

The aim of this chapter is to explore the evidence for both relative and absolute decoupling. It concentrates in particular on trends in the consumption of finite resources and the emission of carbon. These examples don’t exhaust the concerns associated with a continually growing economy. But they are already of immediate concern and illustrate clearly the scale of the problem.

How much decoupling has been achieved in these examples? How much needs to be achieved? Is it really possible for a strategy of ‘growth with decoupling’ to deliver ever-increasing incomes for a world of nine billion people and yet remain within ecological limits? These questions are central to this study.

12.2 Relative decoupling

Put very simply, relative decoupling is about doing more with less: more economic activity with less environmental damage; more goods and services with fewer resource inputs and fewer emissions. Decoupling is about doing things more efficiently. And since efficiency is one of the things that modern economies are good at, decoupling has a familiar logic and a clear appeal as a solution to the dilemma of growth.

Resource inputs represent a cost to producers. So the profit motive should stimulate a continuing search for efficiency improvement in industry to reduce input costs. Some evidence supports this hypothesis. For example, the amount of

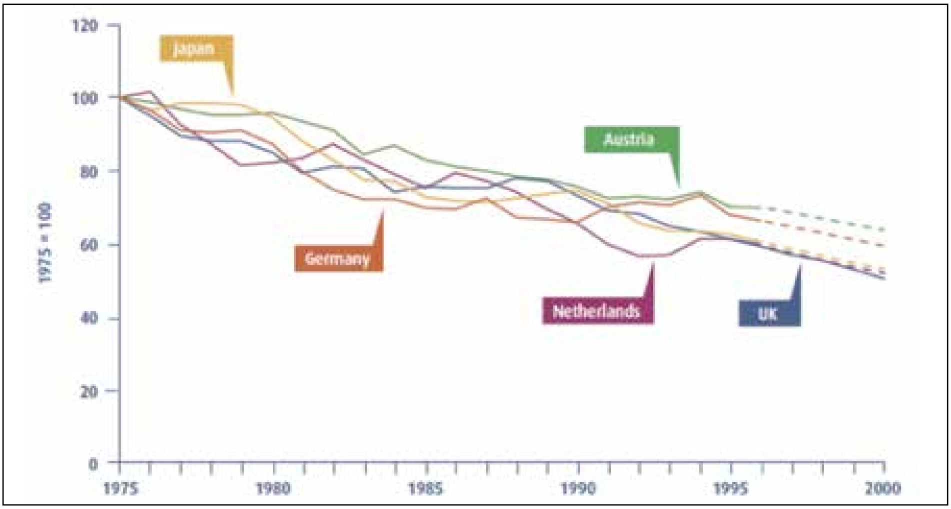


Figure 12.1 Relative Decoupling in OECD countries 1975–20007 (Source: Prosperity without Growth, p. 49, http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf)

primary energy needed to produce each unit of the world's economic output has fallen more or less continuously over most of the last half century. The global 'energy intensity' is now 33% lower than it was in 1970.

These gains have been most evident in the advanced economies. Energy intensities have declined three times faster in the OECD countries over the last 25 years than they have in non-OECD countries. Energy intensity in both the US and the UK is some 40% lower today than it was in 1980.

Outside the most advanced nations, the pattern has been much less clear. Even in some southern European countries (Greece, Turkey, Portugal e.g.) energy intensity has increased in the last twenty five years. And in emerging economies and developing nations, achievements have been very mixed.

Across the Middle East, energy intensity more than doubled between 1980 and 2006; in India it increased at first but has declined slowly since the peak in 1993. In China, energy intensity fell by over 70% to the turn of the 21st Century but has now begun to climb again.

Overall, however, energy intensities declined significantly during the last three decades, across the OECD countries in particular. The same is true of material intensities more generally. Figure 12.1 shows a measure of material intensity for five advanced nations, including the UK, over the final quarter of the 20th Century. The Figure shows clear evidence of 'relative decoupling'.

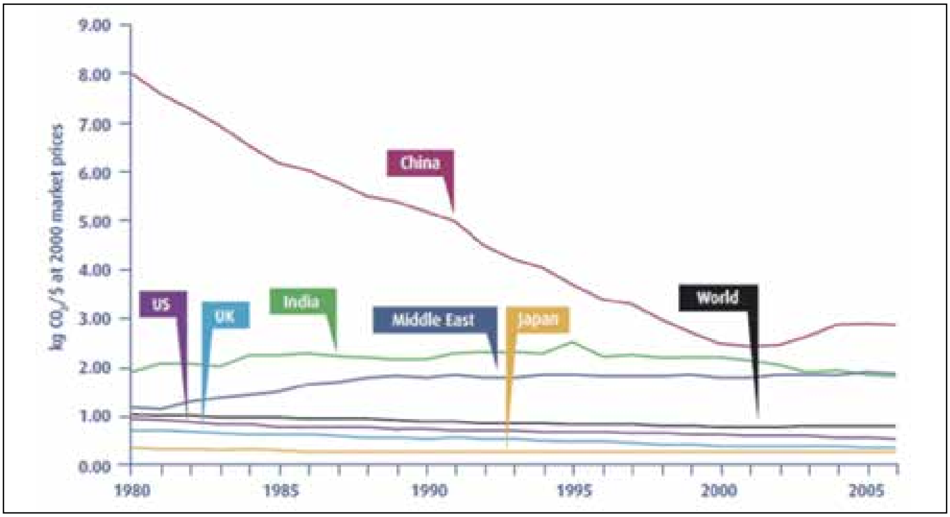


Figure 12.2 CO_2 intensity of GDP across nations: 1980–20067 (Source: Prosperity without Growth, p. 49, http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf)

Not surprisingly, improved resource efficiency is also leading to declining emission intensities. Figure 12.2 shows the changing carbon dioxide intensity of GDP over the last 25 years. The global carbon intensity declined by almost a quarter from just over 1 kilogram of carbon dioxide per US dollar (kgCO_2/$) in 1980 to 770 grams of carbon dioxide per US dollar (gCO_2/$) in 2006. Again, steady improvements across the OECD countries were accompanied by a slightly more uneven pattern across non-OECD countries.

Significant growth in carbon intensity occurred across the Middle East and during the earlier stages of development in India. China witnessed some striking improvements early on. But these have been partly offset by increasing carbon intensity in recent years. Worryingly, the declining global trend in carbon intensity has also faltered in recent years, even increasing slightly since its low point in 2000.

Clearly, there is little room for complacency here. The efficiency with which the global economy uses fossil resources and generates carbon dioxide emissions is improving in some places. But overall we are making faltering progress at best.

To make matters worse, relative decoupling is barely half the story. It measures only the resource use (or emissions) per unit of economic output.

For decoupling to offer a way out of the dilemma of growth, resource efficiencies must increase at least as fast as economic output does. And they must

Box 12.1 The Rebound Effect

In the midst of the current transition we are encountering one serious obstacle to the immaterialization of consumption. It is 'the rebound effect'. This means that the total material use in consumption increases by more than the amount of savings of resources brought by dematerialization of production. It is partly explained by population growth and lack of solidarity of economic policies. Analyses depicts e.g. how the increase in world energy consumption well exceeds the savings from efficiency improvements. The rebound effect is also known as Jevons paradox, or 'back-fire'. See further Sustainable development as post-modern culture by Pentti Malaska, http://www.balticuniv.uu.se/index.php/boll-on-line-library/819-a-sustainable-baltic-region).

continue to improve as the economy grows, if overall burdens aren't to increase. To achieve this more difficult task, we need to demonstrate absolute decoupling. Evidence of this is much harder to find.

12.3 Absolute decoupling

Despite declining energy and carbon intensities carbon dioxide emissions from fossil fuels have increased by 80% since 1970. Emissions today are almost 40% higher than they were in 1990 – the Kyoto base year – and since the year 2000 they have been growing at over 3% per year. This illustrates some relative decoupling: the world GDP has risen faster than carbon dioxide emissions over the last eighteen years. But there is no absolute decoupling here. And a surge in world consumption of coal has increased the rate of growth in carbon dioxide emissions since the year 2000.

What's true for fossil resources and carbon emissions is true for material throughputs more generally. Figure 12.3 illustrates direct material consumption for the same five OECD countries shown in Figure 12.2. Despite very clear evidence of relative decoupling in the earlier figure, there is far less evidence here of an absolute decline in material consumption. The best that can be observed – in only a couple of countries – is something of a stabilisation in resource requirements, particularly since the late 1980s. But even this finding is not entirely to be trusted. The problem is that it's difficult to pick up all the resources embedded in traded goods.

The measure shown here – direct material consumption – does its best to identify traded flows of specific resources. But it misses out on the resources (and emissions) used to manufacture finished and semi-finished products abroad.

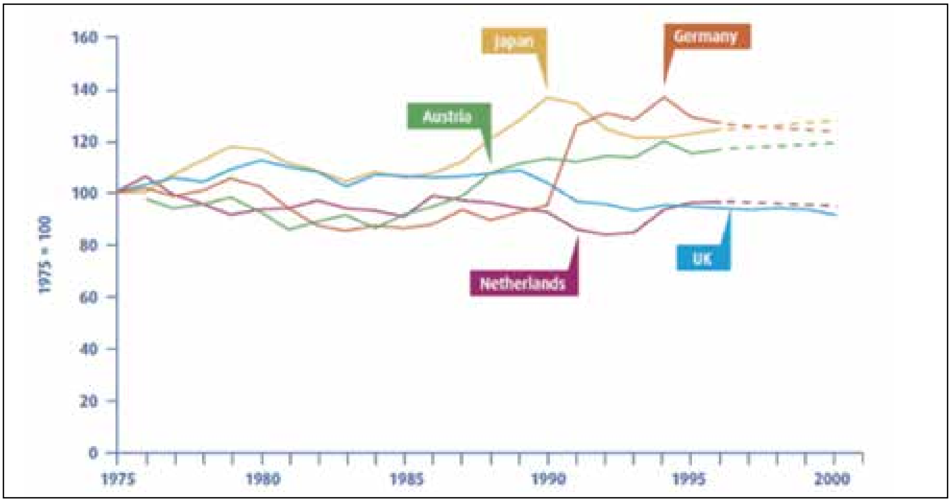


Figure 12.3 Direct Material Consumption in OECD Countries: 1975–2000 (Source: Prosperity without Growth, p. 51, http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf)

This question is important precisely because of the structure of modern developed economies, which have typically tended to move progressively away from domestic manufacturing. Unless the demand for consumer goods also declines, more and more finished and semi-finished goods need to be imported from abroad. And since concepts like direct material consumption omit such accounts, Figure 12.3 underestimates the resource requirements of developed economies.

Correcting this failing calls for more sophisticated resource and economic models than are currently available. In the case of carbon dioxide, however, several recent studies for the UK have confirmed that national accounts systematically fail to account for the 'carbon trade balance'. In other words, there are more (hidden) carbon emissions associated with UK consumption patterns than appear from the numbers we report to the United Nations under the

Climate Change Convention. In fact, this difference is enough to undermine the progress made towards the UK's Kyoto targets. An apparent reduction in emissions of 6% between 1990 and 2004, as reported under UN FCCC guidelines is turned into an 11% increase in emissions, once emissions embedded in trade are taken into account.

Without more detailed work, it's difficult to know whether this pattern is true more generally for material resources. But given the trend away from manufacturing, it's clearly wise to view Figure 12.3 with some caution. There is an outside

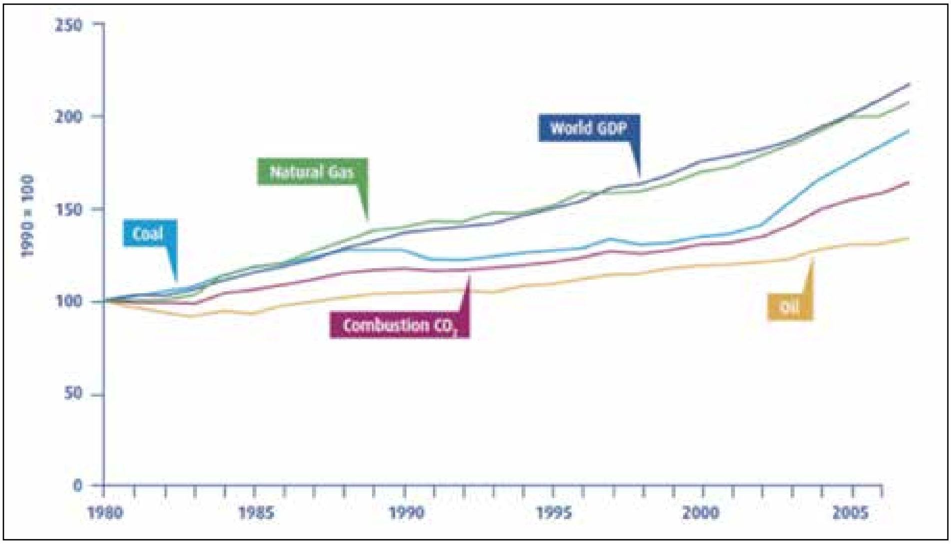


Figure 12.4 Trends in Fossil Fuel Consumption and Related CO_2: 1980–2007 (Source: Prosperity without Growth, p. 51, http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf)

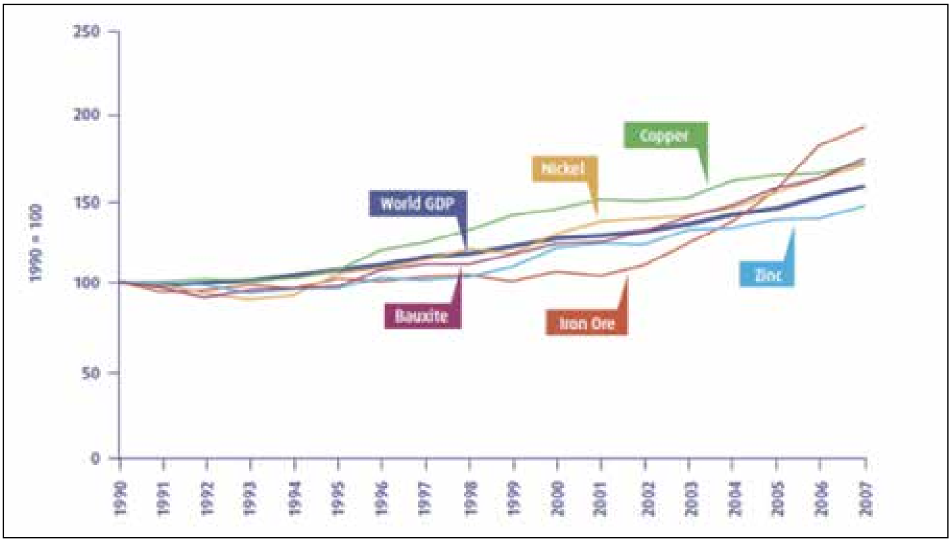


Figure 12.5 Global Trends in Primary Metal Extraction: 1990–2007 (Source: Prosperity without Growth, p. 51, http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf)

chance that some stabilisation of resource consumption has occurred. But Figure 12.3 doesn't provide a lot of confidence in absolute decoupling, even within the advanced economies.

Ultimately, in any case, what count most in terms of global limits are worldwide statistics. Both climate change and resource scarcity are essentially global issues. So the final arbiter on the feasibility of absolute decoupling – and the possibilities for escaping the dilemma of growth – are worldwide trends. Figure 12.4 confirmed a rising global trend in fossil fuels and carbon emissions. Figure 12.5 shows the global trend in the extraction of another vital set of finite resources – metal ores. What's striking from Figure 12.5 is not just the absence of absolute decoupling. There is little evidence of relative decoupling either. Some improved resource efficiency is evident in the earlier years, but this appears to have been eroded more recently.

Particularly notable is the increased consumption of structural metals. Extraction of iron ore, bauxite, copper and nickel is now rising faster than world GDP.

Reasons for this are not particularly hard to find. China's hunger for iron ore is well-documented. As the emerging economies build up their infrastructures, the rising demand for structural materials is one of the factors that put an upward pressure on commodity prices during 2007 and the first half of 2008. The impact on certain non-metallic minerals is just as striking. Worldwide cement production has more than doubled since 1990, surpassing growth in world GDP by some 70 percentage points. Global resource intensities (the ratios of resource use to GDP), far from declining, have increased significantly across a range of non-fuel minerals. Resource efficiency is going in the wrong direction. Even relative decoupling just isn't happening.

It's clear from this that history provides little support for the plausibility of decoupling as a sufficient solution to the dilemma of growth. But neither does it rule out the possibility entirely. A massive technological shift; a significant policy effort; wholesale changes in patterns of consumer demand; a huge international drive for technology transfer to bring about substantial reductions in resource intensity right across the world: these changes are the least that will be needed to have a chance of remaining within environmental limits and avoiding an inevitable collapse in the resource base at some point in the (not too distant) future.

The message here is not that decoupling is unnecessary. On the contrary, absolute reductions in throughput are essential. The question is, how much is achievable? How much decoupling is technologically and economically viable? With the right political will, could relative decoupling really proceed fast enough to achieve real reductions in emissions and throughput, and allow for continued economic growth? These critical questions remain unanswered by those who propose decoupling as the solution to the dilemma of growth. More often than not, the crucial distinction between relative and absolute decoupling isn't even elucidated.

It's far too easy to get lost in general declarations of principle: growing economies tend to become more resource efficient; efficiency allows us to decouple emissions from growth; so the best way to achieve targets is to keep growing the economy.

This argument is not at all uncommon in the tangled debates about environmental quality and economic growth. It contains some partial truths – for example, that some efficiency improvements occur in some advanced economies. It draws some support from some limited evidence on air pollutants such as sulphur dioxide and particulates. These emissions sometimes show an inverted-U shaped relationship with economic growth: emissions grow in the early stage of growth but then peak and decline. But this relationship only holds, according to ecological economist Douglas Booth, for local, visible environmental effects like smoke, river water quality and acid pollutants. It isn't uniformly true even for these pollutants. And it simply doesn't exist at all for key indicators of environmental quality such as carbon emissions, resource extraction, municipal waste generation and species loss.

As an escape from the dilemma of growth it is fundamentally flawed. Ever greater consumption of resources is a driver of growth. As industrial ecologist Robert Ayres has pointed out: 'consumption (leading to investment and technological progress) drives growth, just as growth and technological progress drives consumption.' Protagonists of growth seldom compute the consequences of this relationship.

12.4 The Arithmetic of Growth

Arithmetic is key here. A very simple mathematical identity governs the relationship between relative and absolute decoupling. It was put forward almost forty years ago by Paul Ehrlich and John Holdren. The Ehrlich equation tells us quite simply that the impact (I) of human activity is the product of three factors: the size of the population (P), its level of affluence (A) expressed as income per person, and a technology factor (T), which measures the impact associated with each dollar we spend.

$$I = P \times A \times T$$

Box 12.3:
Unravelling the Arithmetic of Growth

The Ehrlich equation states that environmental impact (I) is a product of population (P) times affluence or income level (A) times the technological intensity (T) of economic output.
I = P x A x T.

For carbon dioxide emissions from fuel combustion, for example, the total emissions are given by the product of population (P) times income (measured as dollars of GDP/person) times the carbon intensity of economic activity (measured as $gCO_2/\$$):

C = P x \$/person x $gCO_2/\$$

Using this arithmetic for the year 2007, when the global population was about 6.6 billion, the average income level in constant 2000 dollars (at market prices) was \$5,900, and the carbon intensity was 760 $gCO_2/\$$, we find that the total carbon dioxide emissions C were:

6.6 x 5.9 x 0.77 = 30 billion tonnes of CO_2.

In 1990, when the population was only 5.3 billion and the average income was \$4,700 but carbon intensity was 860 $gCO_2/\$$, total carbon dioxide emissions C were given by:

5.3 x 4.7 x 0.87 = 21.7 billion tonnes of CO_2.

These numbers are confirmed against those reported in the Energy Information Administration's International Energy Annual. The cumulative growth in emissions between 1990 (the Kyoto base year) and 2007 was 39% (30/21.7 = 1.39) with an average growth rate in emissions (ri) of almost 2% (ri = (1.39)1/17 – 1 = 1.96%).

For as long as the T factor is going down, then we are safe in the knowledge that we have relative decoupling. But for absolute decoupling we need I to go down as well. And that can only happen if T goes down fast enough to outrun the pace at which population (P) and income per capita (A) go up. Over the last five decades this has been a tough ask. Both affluence and population have gone up substantially, each being about equally responsible for the overall five-fold growth in the economy.

In recent years, the affluence factor has exceeded the population factor in driving growth. But both are clearly important, as Ehrlich himself clearly recognised. And neither has proved particularly tractable to policy. Increasing affluence has been seen as synonymous with improved wellbeing.

Advocating limits to population growth has been seen as contravening basic human liberties. Ironically, both these preconceptions are wrong. Increasing incomes don't always guarantee wellbeing and sometimes detract from it. And the fastest population growth has occurred in the developing world – driven not by liberty but by a lack of education and inadequate access to contraception.

Nonetheless, the intractability of addressing both population and income has tended to reinforce the idea that only technology can save us. Knowing that efficiency is key to economic progress, it is tempting to place our faith in the possibility that we can push relative decoupling fast enough that it leads in the end to absolute decoupling. But just how feasible is this?

There is a convenient 'rule of thumb' to figure out when relative decoupling will lead to absolute decoupling. In a growing population with an increasing average income, absolute

decoupling will occur when the rate of relative decoupling is greater than the rates of increase in population and income combined. With this rule of thumb in mind, it's instructive to explore what's happened historically (and why) to global carbon dioxide emissions. Carbon intensities have declined on average by 0.7% per year since 1990. That's good; but not good enough. Population has increased at a rate of 1.3% and average per capita income has increased by 1.4% each year (in real terms) over the same period. Efficiency hasn't even compensated for the growth in population, let alone the growth in incomes.

Instead, carbon emissions have grown on average by 1.3 + 1.4-0.7 = 2% per year, leading over 17 years to an almost 40% increase in emissions (Box 12.3).

The same rule of thumb allows us a quick check on the feasibility of decoupling carbon emissions from growth in the future. The IPCC's Fourth Assessment report suggests that achieving a 450 ppm stabilisation target means getting global carbon dioxide emissions down to below 4 billion tonnes per annum by 2050 or soon after. This would be equivalent to reducing annual emissions at an average rate of 4.9% per year between now and 2050.

But income and global population are going in the opposite direction. According to the UN's mid-range estimate, the world's population is expected to reach nine billion people by 2050 – an average growth of 0.7% each year. Under business as usual conditions, the decline in carbon intensity just about balances the growth in population and carbon emissions will end up growing at about the same rate as the average income -1.4% a year. It might not sound much, but by 2050, under these assumptions, carbon emissions are 80% higher than they are today. Not quite what the IPCC had in mind.

To achieve an average year-on-year reduction in emissions of 4.9% with 0.7% population growth and 1.4% income growth T has to improve by approximately 4.9 + 0.7 + 1.4 = 7% each year – almost ten times faster than it is doing right now.

By 2050 the average carbon content of economic output would need to be less than 40 gCO_2/\$, a 21-fold improvement on the current global average. In fact, things could get even worse than this. At the higher end of the UN's population estimates – in a world of almost 11 billion people – business as usual would more than double global carbon emissions over today's level. Achieving the 2050 target in these circumstances would put even more pressure on technological improvements, to drive the carbon intensity of output down to less than 30 gCO_2/\$.

Notably, this would still be a deeply unequal world. Business-as-usual income growth is usually taken to mean a steady 2 or 3% growth rate in the most developed countries while the rest of the world does its best to catch up – China and India leaping ahead at 5-10% per annum at least for a while, with Africa, South America and parts of Asia languishing in the doldrums for decades to come. In most of these scenarios, both the incomes and the carbon footprints of the developed nations would be more than an order of magnitude higher by 2050 than those in the poorest nations.

If we were really serious about fairness and wanted the world's nine billion people all to enjoy an income comparable with EU citizens today, the economy would need to grow 6 times between now and 2050, with incomes growing at an average rate of 3.6% a year. Achieving the IPCC's emission target in this world means pushing down the carbon intensity of output by 9% every single year for the next forty or so years. By 2050, the average carbon intensity would need to be 55 times lower than it is today at only 14 g CO_2/\$.

Box 12.4 The Stern Review on the Economics of Climate Change

is a 700-page report released for the British government on 30 October 2006 by economist Nicholas Stern, at the London School of Economics. The report discusses the effect of global warming on the world economy.

The Stern Review's main conclusion is that the benefits of strong, early action on climate change far outweigh the costs of not acting. The potential impacts of climate change on water resources, food production, health, and the environment - the overall costs of climate change - will be equivalent to losing at least 5% of global gross domestic product (GDP) each year, now and forever. The Review proposes that one percent of global GDP per annum is required to be invested to avoid the worst effects of climate change. In June 2008, Stern increased the estimate for the annual cost of achieving stabilization between 500 and 550 ppm CO_2e to 2% of GDP to account for faster than expected climate change.

The Review states that climate change is the greatest and widest-ranging market failure ever seen, presenting a unique challenge for economics. The Review provides prescriptions including environmental taxes to minimize the economic and social disruptions. (Source: Wikipedia)

And this scenario still hasn't factored in income growth in the developed nations. Imagine a scenario in which incomes everywhere are commensurate with a 2% increase per annum in the current EU average income. The global economy grows almost 15 times in this scenario and carbon intensity must fall by over 11% every single year. By 2050 the carbon content of each dollar has to be no more than 6 gCO_2/$. That's almost 130 times lower than the average carbon intensity today.

Beyond 2050, of course, if growth is to continue, so must efficiency improvements. With growth at 2% a year from 2050 to the end of the century, the economy in 2100 is 40 times the size of today's economy. And to all intents and purposes, nothing less than a complete decarbonisation of every single dollar will do to achieve carbon targets. Needless to say, these numbers look even worse, if the higher UN population projections materialise. Although conversely, of course, more robust population policies would reduce the pressure on technology.

12.5 Stark choices

Playing with numbers may seem like dancing angels on the head of a pin. But simple arithmetic hides stark choices. Are we really committed to eradicating poverty? Are we serious about reducing carbon emissions? Do we genuinely care about resource scarcity, deforestation, biodiversity loss? Or are we so blinded by conventional wisdom that we daren't do the sums for fear of revealing the truth?

One thing is clear. Business as usual is grossly inadequate, as even the International Energy Agency – the world's energy watchdog – now accepts. Their 'Reference' scenario has the demand for primary energy growing by 45% by 2030, on-track for the 80% hike in carbon emissions alluded to above.

The IEA's 'Stabilisation' scenario reveals the scale of the challenge. 'Our analysis shows that OECD countries alone cannot put the world onto a 450 ppm trajectory, even if they were to reduce their emissions to zero', the World Energy Outlook 2008 admits.

The report also highlights the scale of investment that is likely to be needed over the coming decades. Stabilising carbon emissions (and addressing problems of energy security) requires a whole-scale transition in global energy systems. Technological change is essential, with or without growth. Even a smaller economy would face this challenge: declining fossil energy requirements and substantially reduced carbon emissions are vital.

We can never entirely discount the possibility that some massive technological breakthrough is just round the corner. But it's clear that early progress towards carbon reduction will have to rely on options that are already on the table:

enhanced energy efficiency, renewable energy and perhaps carbon capture and storage.

Just how much decoupling could be achieved in this way is an open question. The truth is, we haven't yet tried that hard to achieve it. As Paul Ekins pointed out in his contribution to Redefining Prosperity, current policies barely scratch the surface of what could be done to deliver decoupling. Substantial early investment in low carbon technologies is obviously essential. The need for this kind of investment could transform the economics of the 21st Century. Its impact on global growth is far from certain. The Stern Review famously argued that 'the annual costs of achieving stabilisation...are around 1% of global GDP.'30 But the stabilisation target was a less punishing one (550 ppm) than is now believed to be necessary.

Stern himself subsequently revised his cost estimate to 2% of GDP on the grounds that a stabilization target of 500 ppm was now needed because climate change was proceeding faster than previously anticipated. The UK Climate Change Committee's first report published in December 2008 came up with costs consistent with Stern. Accountancy firm Price Waterhouse Coopers estimated the costs of achieving a 50% reduction in global carbon emissions at 3% of global GDP.

Though clearly substantial, even these numbers may underestimate the economic impact of addressing climate change. 'The easy compatibility between economic growth and climate change, which lies at the heart of the Stern Report, is an illusion,' claims energy economist Dieter Helm. Stern's microeconomic appraisals of cost suffer from serious 'appraisal optimism', he suggests, assuming that wholesale transformation of energy systems can be achieved by scaling up marginal cost estimates.

Helm also attacks the macro-economics of current stabilisation scenarios. Not only could carbon abatement policies interfere more seriously with productivity than many macro-economic assessments suggest, but early climate change impacts could themselves reduce potential growth. Assuming that economic growth simply rolls onwards in the face of high mitigation and adaptation costs is untenable, claims Helm.

Besides all this, none of the existing stabilization scenarios (including those in the Stern review) deliver global income parity. Income growth in the developed nations is taken as read. Parts of the developing world are assumed to catch up a little with the richer nations. But no attempt is made to develop scenarios in which incomes are distributed equally across nations. Unless growth in the richer nations is curtailed or some kind of completely unforeseen technological breakthrough happens, the carbon implications of a truly shared prosperity are even more daunting to contemplate.

The truth is that there is as yet no credible, socially just, ecologically-sustainable scenario of continually growing incomes for a world of nine billion people.

In this context, simplistic assumptions that capitalism's propensity for efficiency will allow us to stabilise the climate or protect against resource scarcity are nothing short of delusional. Those who promote decoupling as an escape route from the dilemma of growth need to take a closer look at the historical evidence – and at the basic arithmetic of growth.

Resource efficiency, renewable energy and reductions in material throughput all have a vital role to play in ensuring the sustainability of economic activity. But the analysis in this chapter suggests that it is entirely fanciful to suppose that 'deep' emission and resource cuts can be achieved without confronting the structure of market economies.

Chapter 12 sources:

The UK Sustainable Development Commission Report "Prosperity without growth? The transition to a sustainable economy" by Tim Jackson, Chapter 4 The Myth of Decoupling
http://www.sd-commission.org.uk/data/files/publications/prosperity_without_growth_report.pdf

V
Implementing Sustainable Materials Management

Chapter 13
Industrial ecology and cleaner production strategies

13.1 Sustainable production

In its beginning industrial production was connected to chimneys with dirty smoke, effluents to rivers and mountains of bad-smelling solid waste. This has been improved over the years but still in the end of the last century industrial production caused much pollution. This is obviously not sustainable and has to change. An equally important aspect is the resource use in industrial production, may it be metal ore, biomass such as wood, or the large amounts of energy, quite often fossil. In contrast sustainable production deals with how to improve and manage production in a manner which is resource efficient, non-polluting and produces products which themselves are environmentally friendly and sustainable.

The importance of developing sustainable production and consumption patterns cannot be overstated. It was singled out in the 1992 UNCED Rio conference as the main reason for the global environmental crisis and in the Plan of Implementation at the Johannesburg conference 2002 it was a main concern. In Agenda 21 we read: "The major cause of the continued deterioration of the global environment is the unsustainable pattern of consumption and production, particularly in industrialized countries".

Production is part of a system. It needs to be seen together with the resources extracted, the products produced and how they are used, and finally the waste, which all products eventually will become. This is the life-cycle of a product. The pattern of production in industrial society is using enormous amounts of natural resources, is often inefficient and leads to waste accumulation. To become sustainable production needs to be much more like what we see in nature: in nature resources are recycled, energy is based on sun, and products are extremely efficient.

Environmental impact along the life cycle is calculated according to well-established methods in a so-called Life Cycle Assessment, LCA. (See further chapter 7). LCA is much used to compare different production methods or products. A classical question to be answered by an LCA is "Is it better to use a reusable glass or a through-away plastic bottle for drinks?" The comparison needs to take into account the resource used for producing the glass bottle including energy, transporting it back to the factory, cleaning it, while the plastic bottle only uses the oil to make plastic. In a classical analysis it turned out that the glass bottle needs to be reused 11 times to be better. Even if a proper complicated LCA is not conducted each person should consider, be aware of, the life cycle of products. Life cycle thinking is the beginning of a systems approach to production. LCA can be seen as both a management tool and as a way to integrate environmental concern into product development.

Pollution from industries was long understood as merely a constraint from the environment and thus a burden and a cost for the production. The so-called end-of-pipe approach was used to combat pollution. End-of-pipe means that effluents, emissions and waste are treated to remove pollutants. But eventually it was understood that pollution was rather a sign that the production processes themselves were not working well. The resources should be used for products not pollutants! The change of production processes to non-polluting and resource efficient processes is called cleaner production, CP measures. Cleaner production is in the economic, environmental and social interest of producers and have since the 1990s been implemented in many industries. In this chapter Cleaner Production is pointed out as a main road for how to approach a more sustainable industrial production.

In this chapter we will summarise some tools and methods used to reduce material flows and environmental impact in industry in order to approach sustainable prodction.

13.2 Industrial Ecology

The concept of industrial ecology evolved in the early 1990s. So far, there is no generally accepted definition of industrial ecology. Jelinski et al. define it as a concept in which an industrial system is viewed not in isolation from its surrounding systems but in concert with them.

Industrial ecology seeks to optimize the total materials cycle from virgin material to finished material, to component, to product, to waste product, and to ultimate disposal. While industrial metabolism explores the material and energy flows through the industrial economy, industrial ecology goes farther. Similar to what is known about natural ecosystems, the approach strives to develop methods to restructure the economy into a sustainable system. The industrial system is seen as a kind of special biological ecosystem or as an analogue of the natural system.

Other pioneers of industrial ecology define it even as the science of sustainability. In this context, it is worth mentioning that sustainability has not only an ecological but also social and economic dimensions. Clearly, the variety of topics and approaches demonstrates the breadth of the field that industrial ecology attempts to span. This fact is also used to criticize the approach as being vague and mired in its own ambiguity and weakness. The legitimacy of the analogy between industrial and ecological ecosystems is also questioned.

The basic design principles in industrial ecology asks for the utilization of Material Flows Analysis, MFA. It can be used to

1. Controlling pathways for materials use and industrial processes
2. Creating loop-closing industrial practices
3. Dematerializing industrial output
4. Systematizing patterns of energy use
5. Balancing industrial input and output to natural ecosystem capacity

MFA contributes to a better understanding of industrial metabolism, as it requires a description of the most relevant material flows through the industrial economy. This encompasses the selection of relevant materials on the "goods level" (e.g., energy carriers, mineral construction materials, steel, fertilizers) and on the "substance level" (e.g., carbon, iron, aluminium, nitrogen, phosphorus, cadmium). The system boundaries must be defined in such a way that the pathways of materials are covered from the cradle (exploitation) to the grave (final sink for the material). The results of an MFA reveal the most important processes during the life cycle of a material, detect relevant stocks of the material in the economy and the environment, show the losses to the environment and the final sinks, and track down internal recycling loops.

Additionally, MFA can be used to compare options on the process level and at the system level.

Second, the concept's imminent call for closed loops (realized, for example, in the form of a cluster of companies, a so-called industrial symbiosis) requires information about the composition of wastes to become feedstock again and about the characteristics of the technological processes involved. In particular, the implementation of industrial loops requires controls by appropriate MFA, since loops have the potential of accumulating pollutants in goods and stocks. The fact that waste is recycled or reused is not yet a guarantee for a positive result. Two negative examples are the use of contaminated fly ash in cement production or the reuse of animal protein causing bovine spongiform encephalopathy (BSE), known as "mad cow" disease.

A third objective in industrial ecology is dematerialization. This can be achieved by providing functions or services rather than products. Again, MFA can be used to check whether a dematerialization concept (e.g., the paperless office) succeeds in practice. Other ways of dematerialization are to prolong the lifetime of products or to produce lighter goods. Up to now, most applications of MFA have served to investigate the industrial metabolism for selected materials such as heavy metals, important economic goods, or nutrients.

The city of Kalundborg, Denmark, is frequently mentioned as an example of an "industrial ecosystem" in the industrial ecology literature. (See further chapter 15). Materials (fly ash, sulphur, sludge, and yeast slurry) and energy (steam, heat) are exchanged between firms and factories within a radius of about 3 km. Using waste heat for district heating and other purposes (e.g., cooling) has long been recognized as good industrial practice (known as power-heat coupling). The comparatively few material flow links between the actors in Kalundborg show that the concept of (apparently) closed loops is difficult to accomplish in reality. Materials balancing is seen as a major tool to support industrial ecosystems.

13.3 Cleaner production

The production itself is a very important part. It may be improved tremendously by Cleaner Production, CP. The goal of CP is to improve the eco-efficiency in companies by implementing technical or organisational actions. By reducing the negative effects to the environment operating costs are reduced. Cleaner Production works with process integrated - preventive - methods instead of End-of-Pipe solutions. Cleaner Production is good not only for the environment but also for the economy! Of course! You make products efficiently, not pollutants inefficiently.

Sometimes you see the concept of Clean Tech used. It use to explicitly refer to the entire life cycle of a product, from extraction of raw material, to production, use and end-of-life.

The five basic principles of CP are:

- Input-Substitution: Use of less hazardous raw-, auxiliary- or operating materials, Use of operating materials with a longer life-time
- Good Housekeeping: Increasing the Material and Energy efficiency with actions in the process. Try to fetch the (easy) "low hanging fruits" first. Reducing losses due to leakage. Training of employees.
- Internal Recycling: Closing of Material and Energy Loops (Water, Solvents,..) Cascading of Material and Energy streams.

- Technological Optimisation/Change: Changing to a different more efficient technology. This is most often an advanced and difficult step to take.
- Optimisation of the Product: Eco design of products to reduce material intensities and hazardous materials.

The improved management of water in a production process may illustrate both the principle of good housekeeping and internal recycling. The following steps are often needed:

1. Start to monitor water use carefully
2. Install valves to close water when not used
3. Fix "low hanging fruits" (leaks etc)
4. Reuse of wastewater (down-classing of water)
5. Recirculation of cooling water after cooling (closed cooling water system)
6. Recirculation of process water (after specific purification)
7. Redesign of processes, e.g. include counter current rinsing etc.

As seen the optimised treatment of wastewater streams is an important part of the schedule. The overall goal is to reduce the volume of wastewater, not the least by recirculation of process water, often after specific treatment steps, which depends on kind of pollutant, so separate handling of different waste streams may be necessary. If wastewater streams are intermittent it is important to even out peaks by intermittent storing. In many cases we see a tenfold or better reduction of water use, which results not only in cleaner production but considerably better economy: Cost of water decreases, and so does costs of wastewater treatment, as well as cost of chemicals and also personnel.

Technological Change is often a more advanced part of CP in a process. Examples include the dramatic change of technology in the pulp and paper sector the last 20 or so years. Here new ways include completely changed use of water, resulting in a dramatic reduction of water use, new chemistry of bleaching (from chlorine based to chlorine free bleaching) and improved use of black liquor which is formed from lignin in the wood. Another dramatic example is the change in technology in the chlorine-alkali industry. Here mercury based electrodes were used (and is still used in many factories) in the electrolysis of NaCl solutions. This has been exchanged to a membrane based process, which completely avoids the very toxic mercury. This illustrates the application of improved process control, redesign of processes and the substitution of hazardous processes.

Optimisation of the Product, also called ecodesign is a systematic process to improve a product to give it

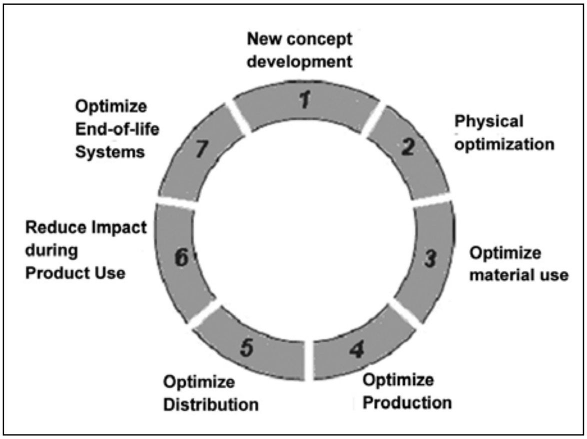


Figure 13.1 The ecodesign strategy wheel (Source: NRC, 2001)

- Increased life-time
- Easier repairing
- Easier de-manufacturing, recycling or deposition
- Use of non-hazardous materials
- Proper design

The steps involved are summarised in Fig. 13.1.

13.4 The Strategies of Green Engineering

Green engineering uses a series of different techniques. These include Ecodesign or Design for Environment (DfE). Ecodesign directs research and development (R&D) teams to develop products that are environmentally friendly. Toxics Use Reduction (TUR) considers the internal chemical risks and potential external pollution risks at the process and worker level. Life Cycle Assessment (LCA) defines the material usage and environmental impact over the life cycle of a product. Green Design may be seen as a comprehensive business strategy that maximises the economic and environmental returns on a variety of innovative pollution prevention techniques. It embeds corporate environmental responsibility into material selection, process and facility design, marketing, strategic planning, cost accounting, and waste disposal.

Green engineering practice requires that concerns about environmental quality include not only production and product use but also useful materials or potential energy embedded in products. An important distinction is the lifetimes

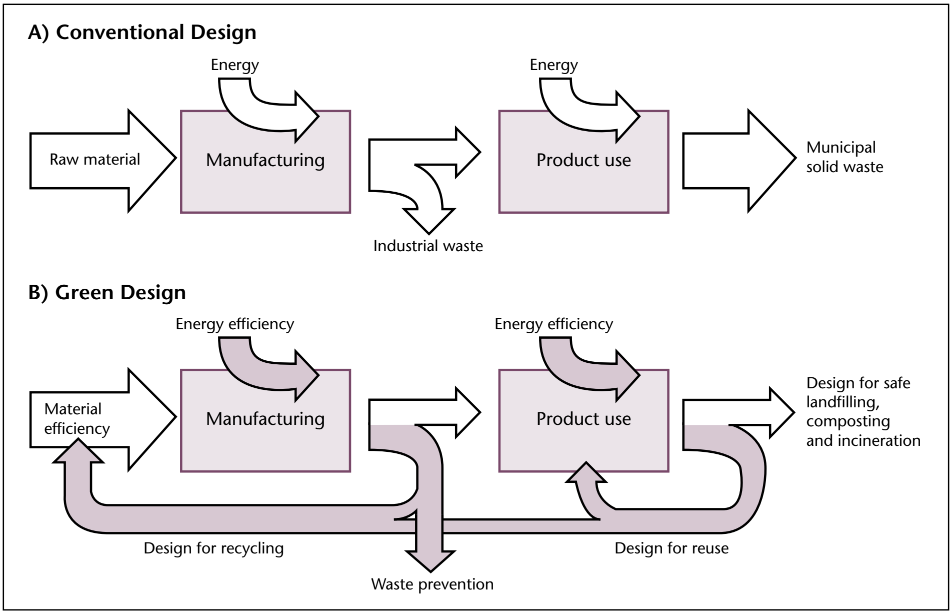


Figure 13.2. How product design affects material flows. Making changes in a product's design reduces overall environmental impact. The green design emphasises the efficient use of material and energy, reduction of waste toxicity, and reuse and recycling of materials. (Source: Reprinted from OTA, 1992).

of products. Some are made to function for a decade or more; others have lives measured in months or weeks; still others are used only once. The designer must adopt different design approaches to these different types of products according to their durability, materials composition, and recyclability. These approaches are implemented in a variety of business processes: product design, production design, materials management, supply chain management, order fulfilment, as well as service, maintenance, and asset recovery. Sustainability strategies in production on several levels can all of them be improved by green engineering.

On the level of the industrial system, the focus is on how one plant is coordinated with other production units in the same area. This is a close parallel to how an ecosystem works and is called industrial ecology or industrial symbiosis. This is a level where changes are slow to introduce since several companies are involved and each one has to agree on the profitability of the change. The essential of the strategy on this level is to organise the material and energy flows in such a way that what is coming out from one unit will be the input in another one.

On the level of the product, the focus is to make products such that they do not pollute and that their use does not require too much energy and other resources input. It is also important that products can be recycled or at least the material in the products can be recycled. They thus need to be designed in a way that makes this possible.

On the level of materials management, the focus is on material flows. We need to find materials which are renewable, we need to reduce the material flows, e.g. by dematerialisation of products, and we need to find materials which are not toxic.

On the level of the production system, the focus is on cleaner production methods. In addition, the up-stream factors are addressed by supply chain management and distribution and transport, and the down-stream factors on recycling as an important part of the end of life system of a product.

13.5 Green chemistry

Many chemical products can be manufactured using a wide variety of synthetic routes. The designer of a chemical process must choose from alternative raw materials, auxiliary materials such as solvents and catalysts, reaction pathways, and reaction conditions, and these design choices can have a significant impact on the overall environmental performance of a chemical process. Green chemistry, refers to the design of chemical products and processes that reduces or eliminates the use and generation of hazardous and polluting substances.

The identification of environmentally preferable chemical processes requires extensive chemical and process knowledge and creativity. Since the number of alternative process pathways is very large and the implications of the alternatives so complex, it is not feasible to develop a systematic, quantitative design tool covering all possible process alternatives of all conceivable products. Ideal chemical reactions would have attributes such as:

- Simplicity
- Safety
- High yield and selectivity
- Energy efficiency
- Use of renewable and recyclable raw and auxiliary materials
- Use of raw materials with no or low content of impurities

In general, chemical reactions cannot achieve all of these goals simultaneously, and it is the task of chemists and chemical engineers to identify pathways that optimise the balance of desirable attributes.

If the agenda specifically includes the use of renewable and recyclable resources and energy generation without fossils, the term sustainable chemistry is often used. Often the concepts of green chemistry and sustainable chemistry are used interchangeably, although green chemistry is the more common expression. Below we will most often use "green chemistry" although we also include issues of renewable resources and avoidance of fossils in energy generation.

The concept of green chemistry is here presented in two basic parts – one qualitative and the other quantitative. A qualitative approach to chemical process design involves raw material selection, selection of auxiliary materials such as solvents, catalysts, and other materials and the selection of reaction pathways and conditions.

Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations. The 12 principles of green chemistry [Anastas and Warner, 1998], provide a road map for implementing green chemistry. These principles have been adopted world-wide.

1. Prevent waste: Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
2. Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity.
3. Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
4. Use renewable feedstocks: Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
5. Use catalysts, not stoichiometric reagents: Minimise waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
6. Avoid chemical derivatives: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
7. Maximise atom economy: Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
8. Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
9. Increase energy efficiency: Run chemical reactions at ambient temperature and pressure whenever possible.

10. Design chemicals and products to degrade after use: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
11. Analyse in real time to prevent pollution: Include in-process real-time monitoring and control during syntheses to minimise or eliminate the formation of by-products.
12. Minimise the potential for accidents: Design chemicals and their forms (solid, liquid, or gas) to minimise the potential for chemical accidents including explosions, fires, and releases to the environment.

13.6 Environmental Law and Management Systems

As the effects of pollution and resource depletion have become more serious, the environmental laws of countries have become stronger. In particular European Union law has been of great importance for improving the environmental performance both of business and the public sector. The increasing environmental threats demand new measures to improve the management of economic activities. That, in turn, prescribes the necessity to take into account ecological requirements in production, development of new products, and management of technological processes, as well as personal and financial management. Today all larger production facilities must have an integrated permit according to the IPPC (Integrated Prevention and Pollution Control) Directive. This raises requirements on resource use (e.g. energy use) and pollution control.

Many production facilities in addition have introduce an Environmental Management Systems, EMS. This is not required by law but has many other advantages. Environmental management is management of an organisation's activities that have or can have an impact on the environment. Figure 13.3 shows the evolution of environmental management since the wave of environmental awareness in the early 1960s. The figure illustrates the short history of the current concept of environmental management.

An EMS is a continuous cycle of planning, implementing, reviewing and improving the processes and actions that an organisation undertakes to meet its environmental targets and requirements. It is a system to comply with the requirements of international standards such as ISO 14001 and EMAS. The definition of an EMS used by ISO 14001 is:

"The part of the overall management system that includes organisational structures, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing achieving, reviewing and maintain-

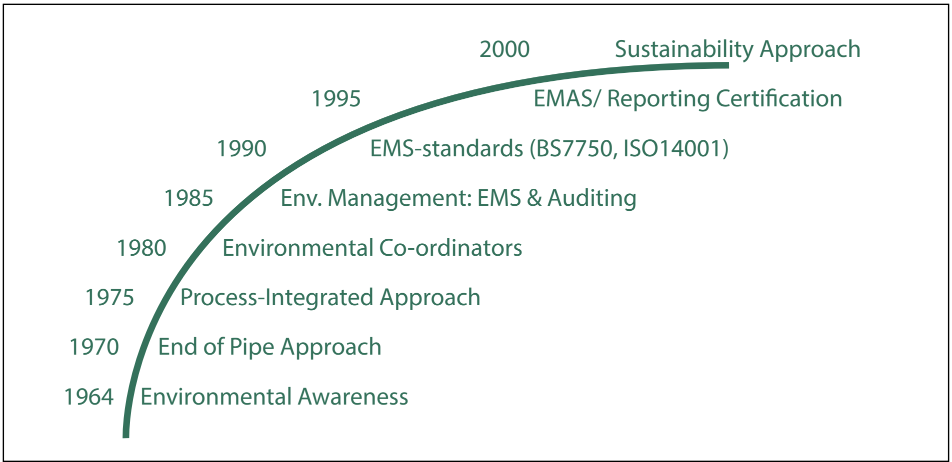


Figure 13.3 Development of the Idea of Environmental Management. (Source: UNEP/ICC/FIDIC, 1996, p. 4 [modified])

ing the environmental policy" [European Committee for Standardization, 1996-08-21, section 3.5].

An EMS thus manages the environmental impacts of an organisation. The expected outcome is continuous improvement in environmental management.

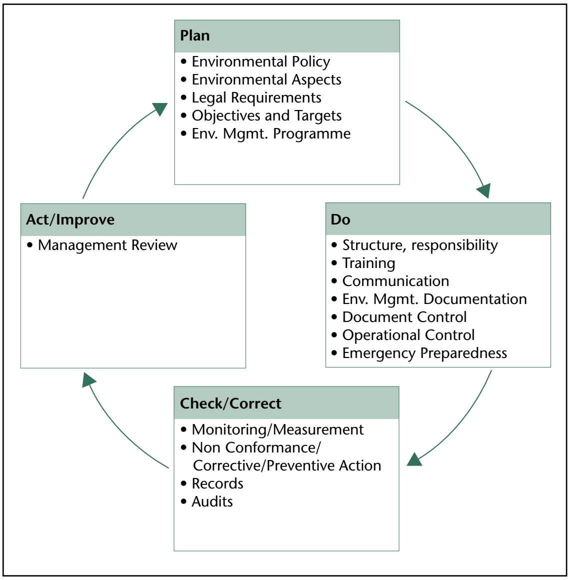
Due to the fact that ISO EMS standards are intended to be applicable in many or even all parts of the world, they are kept very general. Organisations that implement an EMS can thus adapt their EMS exactly to their needs. Organisations that do not have significant environmental impacts themselves may focus their EMS on the environmental performance of suppliers, while organisations with significant environmental impacts may focus on operating more environmentally friendly.

To improve environmental management, an organisation needs to focus not only on what happens but also on why it happens. Over time, the systematic identification and correction of system deficiencies leads to better environmental and overall organizational performance.

Most EMS models (including the ISO 14001 standard) are built on the so-called "Plan, Do, Check, Act" quality management model introduced by Deming in the US in the 1950s. This model puts great emphasis on the concept of continuous improvement. In the following we will explain and discuss in detail the requirements of an efficient EMS according to the basic Deming Cycle (Fig. 13.4)

Most organisations apply Total Quality Management (TQM) principles to some of their operations and activities. An effective EMS is built on TQM con-

Figure 13.4 **Elements of ISO 14001** at Each Step of the Deming Quality Management Model (Source: UNEP/ICC/FIDIC, 1996, p. 7).



cepts. TQM was mostly developed in the US, though the Japanese were the first to visualize its benefits and apply it successfully. They found that if management and employees solved problems together, everyone was committed to the solution. TQM differs from traditional quality improvement techniques in several ways. Most important is that it focuses on system problems. Statistical methods are used to find the reasons for problems, and active employee involvement is required. TQM uses new and alternative methods to improve an organisation's performance while involving all hierarchical levels of staff – from top-management to frontline workers.

Some of the many benefits of a TQM system are:

- Reduction of operating costs.
- Increase in customer satisfaction.
- Improvement of organisation morale.
- Establishment of a process of continuous improvement and business process reengineering.
- Gaining competitive advantage.
- Establishment of a base for ISO registration.

TQM is not only quality management. It involves many more issues such as work safety, risk management, financial management and of course environmental management, depending on the individual situation of every organisation.

TQM influences all employees of an organisation. It enables an organisation to be more flexible and increases the motivation of the employees. As well, it makes it easier to develop long term relations between both an organisation's customers and employees. This great flexibility means that two different EMSs cannot be compared, though they both have to meet the requirements set by the standard setting organisation. An outside observer must be able to understand what an EMS is trying to achieve.

Organisations which have an EMS can be audited by an independent organisation and thereby be certified. Certification of an EMS means that the organisational structures required have been established and that the EMS is designed to achieve continuous improvement. External audits are normally done each third year and internal audits once a year.

ISO 14001 requires organisations to commit themselves to compliance with applicable environmental legislation. As environmental legislation differs widely from country to country, there is a range in level of difficulty to achieve national environmental compliance. This is not as much a problem with EMAS as it is applied in a more homogenous economic area with the same environmental laws applicable.

13.7 Interesting initiatives – the Blue economy

There are many interesting projects which have shown that a very considerable reduction in resource use can be achieved by innovation and good thinking. The factor five project has already been mentioned. Below we will also mention The Blue Economy a Club of Rome project led by Gunter Pauli.

Between 2010 and 2013, Gunter Pauli has presented more than 100 innovations celebrating the scientists and the entrepreneurs, focusing on a breakthrough technology. All 100 cases have been published through multiple media around the world. Daily updates on existing and new cases are presented through Gunter's Twitter account <@MyBlueEconomy>. Based on 20 years of field experience time has come to provide depth and empowerment through cutting edge and creative proposals. We wish to ensure that more people will have the mind-set and the capacity to implement these breakthroughs while understanding how these new business models came about. That is why as of January 2015 the ZERI Foundations and the associated network around the world will publish 100 clusters, sharing how it all started, who provided academic leadership, and where are the entrepreneurs who change the rules of the game.

The Blue Economy principles are:

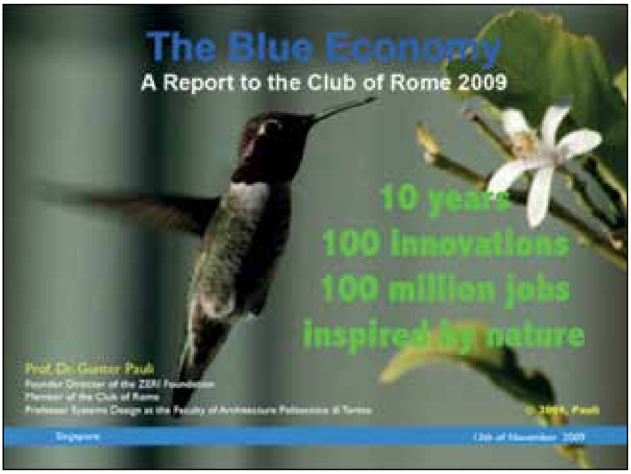


Figure 13.5 The Blue economy book.

- Solutions are first and foremost based on physics. Deciding factors are Pressure and Temperature as found on site.
- Substitute something with Nothing – question any resource regarding its necessity for production.
- Natural systems cascade nutrients, matter and energy – waste does not exist. Any by-product is the source for a new product.
- Nature evolved from a few species to a rich biodiversity. Wealth means diversity. Industrial standardization is the contrary.
- Nature provides room for entrepreneurs who do more with less. Nature is contrary to monopolization.
- Gravity is main source of energy, solar energy is the second renewable fuel.
- Water is the primary solvent (no complex, chemical, toxic catalysts).
- In nature the constant is change. Innovations take place in every moment.
- Nature only works with what is locally available. Sustainable business evolves with respect not only for local resources, but also for culture and tradition.
- Nature responds to basic needs and then evolves from sufficiency to abundance. The present economic model relies on scarcity as a basis for production and consumption.
- Natural systems are non-linear.
- In Nature everything is biodegradable – it is just a matter of time.
- In natural systems everything is connected and evolving towards symbiosis.
- In Nature water, air, and soil are the commons, free and abundant.
- In Nature one process generates multiple benefits.

- Natural systems share risks. Any risk is a motivator for innovations.
- Nature is efficient. So sustainable business maximizes use of available material and energy, which reduces the unit price for the consumer.
- Nature searches for the optimum for all involucrated elements.
- In Nature negatives are converted into positives. Problems are opportunities.
- Nature searches for economies of scope. One natural innovation carries various benefits for all.
- Respond to basic needs with what you have, introducing innovations inspired by nature, generating multiple benefits, including jobs and social capital, offering more with less: This is the Blue Economy

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Chapter 14
Agriculture and resources flow

14.1 Land and landscape

In the western world we see an over-use of land. Human activity dominates 43% of the land surface of the Earth, and we affect twice that area. One-third of all available fresh water is diverted to human use. A full 20% of the net terrestrial primary production of the Earth, the sheer volume of life produced on land every year, is harvested for human purposes. We use more than our fair share of bio productive land, in Europe about 3 times more and in the US 5 times more. The Global South use much less resources, but this situation still constitute an overexploitation of natural resources, especially of fossil energy and forests. Land resources start to become scarce, and we may expect a lack of food in the world in the future. This is corroborated by a steeply increasing price of both food and land and by accelerated foreign investments in land, especially in Africa (land grabbing).

In addition productive land is decreasing. Present land management practices decrease productive land and leads to loss of topsoil and desertification. It is estimated that the loss of topsoil is several hundred times larger than the build-up new soil and new organic content. Global warming in some areas leads to dramatically decreased precipitation and extensive droughts, making large areas unfit for production. In addition, land management practices increase emissions of greenhouse gases (GHG), especially carbon dioxide. Carbon is released through drainage of wetlands, ploughing and all procedures, which increase the access to air, and oxidation of the organic content of topsoil.

Several measures to safeguard land and water have been introduced. Landscape protection, included as one measure in the Biodiversity Convention, cover about 20% of all land surfaces on Earth. Improved land management measures, such as agro-forestry, minimum tillage or use of bio-char, have also been implemented to keep topsoil intact and retain the productive capacity of land, e.g. in several projects in Asia and Africa. Tree plantation is done on a large scale in many places, both for climate mitigation and to improve ecosystem services. New techniques for irrigation in agriculture may dramatically reduce the need for water. Most importantly restoration of ecosystems is possible also at large scale and in areas severely degraded and barren. Such restoration projects demonstrate how soil, greenery and water can return, and people get new livelihoods as food production, economic life and wellbeing is strengthened.

Of the international conventions introduced to protect land and water of the world the most significant are the United Nations Convention to Combat Desertification, UNCCD. It is regrettably the weakest of the Rio conventions as it is lacking its own financing. Agreements on Reducing Emissions from Deforestation and Forest Degradation (REDD) are included in the Climate Convention as it has a great influence on GHG emissions. Wetland preservation is covered by the already old Ramsar Convention. This convention is focused on the preservation of biodiversity rather than on the productive capacity of land and water. There is no convention to protect the oceans of the world, which thus face e.g. unregulated fishing, in addition to e.g. dumping of waste, most seriously plastics which remain in the water. EU directives protect landscape, meadows, and surface waters.

The landscape with its land and water, forests and fields, are of immense importance for the wellbeing of us humans, not only for its physical services such as providing food and water, but also as a living environment, for its cultural and spiritual significance, and as the means by which we are connected to the past and the future of humankind. We should leave planet Earth to our children and grandchildren to enjoy just as much as our ancestors and we have.

14 .2 The challenges of sustainable agriculture

The production, storage, distribution, eating and management of food constitute one of the most important human impacts on the environment. At the same time it is a most essential part of our everyday life and wellbeing. Agriculture covers 40% of the earth's total ice-free land area. It accounts for 70% of the global fresh water use, it employs 3/4 of the world's poorest people and it feeds all of us. Agriculture is the key foundation of human civilization and it is also where most of our present day development problems converge, such as poverty, hunger, environmental degradation and climate change.

Agriculture has developed dramatically. The production and caretaking of harvesting, hunting and fishing once was the main occupation in society. In a modern industrialised country however, only some 2-5% of the population provides all food for the rest. Agriculture and fishing has been industrialised. The production from a hectare of land has been multiplied by new methods, new genetic varieties, and input of nutrients. These developments are still ongoing, e.g.

using GMOs, genetically modified organisms. The GMO technique is by itself not a threat to sustainability of the environment; it is just a method.

Industrialised agriculture depends on linear material flows of nitrogen and phosphorus, which is unsustainable. Phosphorus, mined from a few deposits in the world, will as a non-renewable resource finally become emptied. Nitrogen produced by the industrial fixation of nitrogen gas requires large input of fossil energy and is thus also in this way non-renewable. The global nitrogen flow has due to this doubled and is unsustainable. Excess nitrogen and phosphorus from agriculture is today polluting the water in lakes, coasts and the sea in many parts of the world, and it is causing serious eutrophication.

In contrast, traditional agriculture was carefully managing the circulation of nutrients by returning manure to the fields, composting all organic waste from the preparation of food, and also by returning human excrement to farmland. Among the many efforts made today to re-establish circular flows of nutrients we see how manure, directly or as a residue after biogas production containing most nutrients, are being returned to fields; food waste in cities is collected; and sludge from wastewater treatment plants is used for fertilisation. But it is insufficient and heavy metals and toxic organic chemicals too often pollute organic waste, e.g. sludge from wastewater treatment plants.

Modern agriculture produces an ever-increasing share of meat rather than grains and vegetables. In an industrial society 80% of all we see growing on farmland is food for animals, and large parts of land are used as grazing land for animals. Meat in the menu has been increasing worldwide during the last 100 years and it is still increasing. This is clearly unsustainable and in the future meat in our diet has to decrease significantly. The carbon footprint of one kg of beef is a hundred times that of a kg of potatoes. The excessive production of cheap meat depends on factory-like conditions violating animal welfare. This is un-ethical, and it also leads to low quality food. Today in some countries it is increasingly limited by regulations.

In the western world wasting food adds to the problem. In the EU about 30% of all edible food is wasted, and in the US about 50%. In the US food costs are the lowest, wasting of food the highest and animal rights least respected. An important strategy to reduce the carbon footprint of food is to take care of food better and to reduce meat in the human diet.

Some new approaches have been introduced to increase self-sufficiency and food security. Organic farming and food is increasing rapidly in many places in the world. It relies on circulation of nutrients, limited or no-use of biocides, and secured animal welfare. In agro forestry agriculture is conducted among trees, a system which preserves soil and water and is building new topsoil. Growing food in cities, urban agriculture, uses terraces, roofs and other areas to grow food. Most advanced is permaculture, which builds on ecological design principles, including growing your own organic food, use more rainwater, preservation of landscapes, restoration of ecosystems, and homes built from natural materials.

Food is a global commodity. This is in most cases not a serious concern as such, but it carries a transportation cost. An opposite trend is to increasingly buy food on local markets and from local producers. It leads to a more seasonal diet, often with higher quality and less cost for preservation.

Will there be enough food in the future? How will 9 or 10 billion people be able to eat without undermining the very basis for food production? The problem is aggravated by competition between food and energy crops as well as the continuing degradation of agricultural land. Key changes are needed in this sector to achieve a transition to a sustainable society.

14.3 Carbon flows in agricultural soils

The way we treat ecosystems influences the global flows of carbon. This is already well discussed when it comes to phosphorus and nitrogen. But also the flows of carbon, the major constituent of life on earth, are critically affected by land use and our way to conduct agriculture and forestry in particular. Besides the emissions caused by burning fossil fuels, land use and management has come up as a major concern in connection with climate change since global warming is caused by large-scale changes in the global carbon flows.

Large amounts of carbon are cycling between the atmosphere and ecosystems (about 200 Gigatonnes per year). Thus, natural carbon fluxes due to photosynthesis are about 25 times higher than those caused by the burning of fossil fuels and cement production (7.7 Gigatonnes per year). Clearing of mainly tropical forests for pastures, croplands and infrastructure, are also contributing to human induced carbon emissions (about 1.4 Gigatonnes per year) since carbon in the vegetation is released as carbon dioxide and often also soil carbon stocks are declining after this conversion. About 45% of total human induced carbon emissions (7.7 + 1.4 = 9.1 Gigatonnes) are accumulating in the atmosphere (4.1 Gigatonnes), whereas the remaing parts are adsorbed in the oceans (2.3 Gigatonnes) and terrestrial ecosystems, mainly temperate and boreal forests (2.7 Gigatonnes).

Total amounts of carbon stored in soils down to 1 m depth are about three times higher than those in vegetation and about twice as high as those in the atmosphere. Thus, a change in land use and management that will change soil carbon stocks with 1% will result in a 2% change of atmospheric carbon dioxide. The soil carbon balance has therefore significant impact on our climate.

Soil organic carbon content is a key-indicator for soil fertility since it affects soil structure and is positively correlated with aggregate stability, water infiltration, water holding capacity, nutrient delivery, nutrient use efficiency and soil erosion control. Therefore, keeping reasonable high levels of soil organic carbon is fundamental for sustainable management practices. Excluding plant roots, only about 2% of this carbon is in living soil organisms. The rest, about 98%, is a heterogeneous mixture of soil organic material deriving from vegetation and soil organisms at different stages of decomposition.

Carbon inputs in agricultural systems occur mainly through roots and also a higher proportion of root input compared to above-ground crop residues contributes to the build-up of soil carbon stocks. Cereals like wheat and barley have been bred for thousands of years for optimizing grain yields. Therefore, a lower proportion of assimilated carbon ends in roots and straw and a higher proportion is exported compared with many grassland species. This is the main reasons at many sites for higher carbon stocks under grassland or forests compared to cultivated soils. Intensive tillage methods like mouldboard ploughing may also stimulate decomposition since parts of organic material that were not accessible to microbes maybe exposed through breaking up of soil aggregates.

In some regions, soil tillage has been shown to result in decreasing soil carbon stocks although earlier studies were overestimating this effect. This effect seems to be more pronounced in semi-arid areas like the prairies in the US and Canada. Under more humid conditions, in the eastern part of Canada or in the Baltic Sea region, this effect is probably much smaller or even negligible. However, reduced tillage has many other positive effects. Generally it decreases risks for water and wind erosion and it also reduces cost for labour and diesel and thus, emissions of carbon dioxide. On the other hand, no-till systems favour weeds and the survival of plant pathogenic fungi under certain conditions. Therefore, the need for both herbicides and fungicides increases when reducing tillage intensity.

Figure 14.1 shows a hypothetical evolution of soil carbon over time, from mineral sediments almost free from organic matter to natural grassland or forest vegetation.

At a certain time, land use is changed to agricultural usage which results in lower carbon stocks. Thereafter, agricultural management is changed in order to sequester carbon in soil. The time scale in this example maybe more than 1000 years since it takes hundreds of years until the soil system has adjusted to new conditions, i.e., carbon stocks have reached a dynamic equilibrium (carbon input = carbon output), after the change of land use or management.

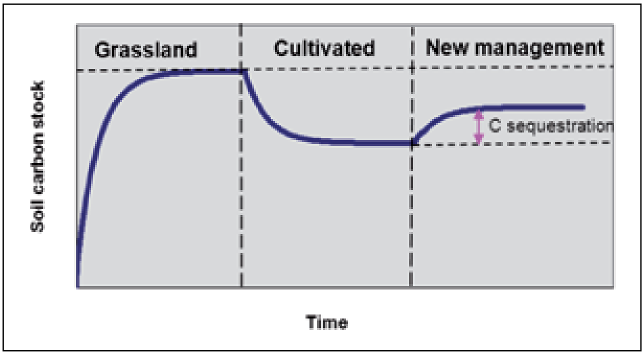

Figure 14.1 Evolution of soil carbon over time. (Source: EHSA Book 1

Since grasslands and forests generally lose carbon upon conversion to agriculture, prevention of land use change in this direction is an effective measure for reducing greenhouse gas emissions. Increasing demand for food, fibres and bioenergy are setting natural ecosystems under pressure and will probably result in changes in land use towards more agriculture in the future. More intensive (higher production per unit area), more efficient and sustainable agricultural and aquacultural production systems have to be developed for minimizing the impact on natural ecosystems.

Carbon sequestration as a mitigation strategy for reducing greenhouse gas emissions can be a win-win strategy, since increased soil carbon is also crucial for soil fertility. Many agricultural practices have the potential to mitigate greenhouse gas emissions. At global level, this potential was estimated to about 1.5 Gigatonnes per year (Smith et al., 2008) excluding potential fossil fuel offsets due to bio-energy production in agricultural systems. If all these potential changes in agronomic practices were included in the carbon trading market, a certain portion of these potentials could be realised depending on the price of carbon dioxide equivalents. Carbon sequestration in soil is one of these options. Carbon inputs are the more controllable part of the soil carbon balance since decomposition is mainly governed by climatic conditions. The most prominent carbon sequestration strategies are therefore practices that result in higher carbon inputs to soil.

However, optimizing a system only in one dimension (e.g. carbon sequestration) may under certain circumstances lead to unwanted consequences like higher nitrous oxide emissions or higher nitrate leaching. Therefore, agricultural systems have to be optimized in many dimensions at the same time for providing enough food, fibers and other ecosystem services for a growing population with less negative impact on climate and nature.

14.4 Nutrient flows in agriculture - nitrogen

The production of sufficient food for a growing population is a major challenge for agriculture. Since agricultural land can only be expanded at the expense of deforestation, crop production must be increased mainly on existing agricultural land. However, higher yields per area require greater input of nutrients. It is therefore essential that limited resources of plant nutrients are used in an efficient way. Knowledge about the amounts and limits of nutrient reserves is vital for decisions on how to utilise resources in an appropriate manner. In order to conserve resources and secure production of food, nutrients must be recycled.

Population growth will not be accompanied by an increase in agricultural land, as the total area of agricultural land can only be marginally expanded. In most cases, only forests are at hand for conversion, and other areas cannot be transformed into agricultural land. In fact, arable land area per person has decreased, from 0.38 hectares in 1970 to 0.23 hectares in 2000, with a projected decline to 0.15 hectares per person by 2050 (FAO, 2008) and consequently crop production on existing arable land must be intensified in order to produce sufficient food.

The demographic trend for increasing urbanization will make towns and cities hot-spots for accumulation of plant nutrients. Food transported to cities results in wastes, from which plant nutrients must be recycled and redistributed. To avoid overloading arable land with recycled nutrients, long-distance transportation from cities back to remote arable land is necessary. However, municipal organic wastes typically have high water and low nutrient contents. For example, dewatered sewage sludge contains 70-80% water and the total content of nitrogen or phosphorus does not exceed 3% of dry matter. The volume of urban wastes to be handled is three- to five-fold larger than the volume of most harvested crops.

In Sweden crop yields have increased at an average rate of 0.5% per year while fertiliser input has remained constant. Efficiency of inputs has improved by about 10% over 20 years. Increasing the efficiency in crop production systems through inputs, farm operations, etc. is a central and driving force in agricultural research. In order to improve the use of organic and mineral fertilisers, detailed knowledge to fine-tune soil and crop management is needed.

A critical question often raised is how long global reserves used for the production of mineral fertilisers will last.

Nitrogen fertiliser production is based on ammonia synthesis, requiring hydrogen (H_2) and nitrogen (N_2) gas. Nitrogen gas is taken from the atmosphere and hydrogen gas is produced from fossil energy, mainly natural gas or through gasification of coal. Hydrogen gas reacts under high pressure and temperature to form ammonia according to the Haber-Bosch reaction, which is an energy-demanding process.

$$N_2 + 3\ H_2 \rightarrow 2\ NH_3$$

Roughly 5% of annual gas consumption in the world is used for ammonia production, of which more than 90% is used in agriculture for the production of different nitrogen fertilisers. Natural gas (CH_4) accounts for about 70% of ammonia production, coal and petroleum coke for the remaining 30%. Hydro-electric power has also been used in some fertiliser plants in the past. Globally, we are using 3.2 trillion cubic metres of natural gas per year of proven reserves of 175 trillion cubic metres. This would mean a life-time of about 50 years.

The dependence of N fertiliser production on fossil fuels is often questioned. Instead, biological nitrogen fixation by legumes is proposed to replace nitrogen fertilizer application. It is also argued that N fertiliser production is too large, threatening the ecological functions of our planet and has been identified as one of our planetary boundaries (See further chapter 4).

However, hydrogen gas can be produced from renewable resources. There are different ways to produce hydrogen gas from biomass, such as (i) anaerobic digestion providing methane; (ii) combustion to form electricity for electrolysis of water; and (iii) thermochemical conversion through pyrolysis and gasification. The last alternative - gasification of biomass - has been investigated by Ahlgren et al. (2009) from a life-cycle perspective using straw or short rotation willow (Salix) as feedstock for an ammonia plant. The results indicate that 1 kg of N can be produced from 2.6 kg dry Salix or 2.7 kg dry straw.

In the straw alternative, no extra land was set aside and the straw was removed from 1 hectare arable land cropped with wheat. In Sweden biomass-based production of nitrogen fertiliser from straw or Salix would provide N fertiliser for an additional 20 or 50 ha, respectively, assuming an application rate of 80 kg per ha of arable land. This shows that nitrogen fertilisers can be produced with renewable energy in the future. Ammonia production according to the Haber-Bosch reaction is an energy-demanding process. However, the energy gain through enhanced photosynthesis is 5 to 10 times higher than the energy required for N fertiliser production.

Renewable energy can replace natural gas as an energy source for N fertiliser production. It is therefore possible to produce N fertilisers from renewable biomass even if fossil energy becomes scarce. This is important because of the crucial role of nitrogen fertiliser for food supply in the world. Smil (2001, 2002) concluded that the Haber-Bosch process for industrial fixation of atmospheric nitrogen provides the very means of survival for 40% of humanity and that only half the current population in the world could be supported by pre-fertiliser farming, even with a mainly vegetarian diet. Thus one has to recognize the immense role of nitrogen fertiliser for human welfare and why fertiliser production will not stop even if fossil resources may be depleted.

14.4 Nutrient flows in agriculture – phosphorus, potassium and sulphur

About 80% of the rock phosphate currently mined is used to manufacture mineral fertilisers. Use for detergents, animal feeds and other applications (metal treatment, beverages, etc.) accounts for approximately 12.5%, 5% and 3%, respectively (Heffer et al., 2005). The global production of rock phosphate amounted to 174 million tonnes in 2008 (IFA, 2010). Depending on its origin, phosphate rock can have widely differing mineralogical, textural and chemical characteristics. Igneous deposits typically contain fluorapatites and hydroxyapatites, while sedimentary deposits typically consist of carbonate-fluorapatites collectively called francolite. Sedimentary deposits account for about 80% of the global production of phosphate rock (Stewart et al., 2005). As high-quality deposits have already been exploited, the quality of the remaining sedimentary phosphorus reserves is declining and the cost of extraction and processing is increasing, mainly due to a lower phosphorus content in the ore (Driver et al., 1999).

It is difficult to forecast how long the existing phosphorus reserves will last. Earlier estimates vary between 50 to 100 years and peak phosphorus is a foreseeable scenario. Including reserve bases would prolong the life-time to around 350 years, based on the current production capacity and excluding an increased demand for phosphorus.

Associated heavy metals such as cadmium and uranium substituting for calcium in the apatite molecule are often present at high levels in phosphate rock, especially that of sedimentary origin. Rock phosphate may contain up to 640 mg cadmium per kg phosphorus and only a minor proportion of phosphorus reserves have a low cadmium content. Most (85-90%) of the cadmium in rock phosphate ends up in fertilisers (Becker, 1989).

A new standard for low cadmium content in phosphorus fertilisers may be required, since the European Food Safety Authority recently reduced the recommended tolerable weekly intake of cadmium from 7 to 2.5 μg per kg body weight, based on new data regarding the toxicity of cadmium to humans (EFSA, 2009). Several countries already restrict cadmium levels in phosphate fertilisers

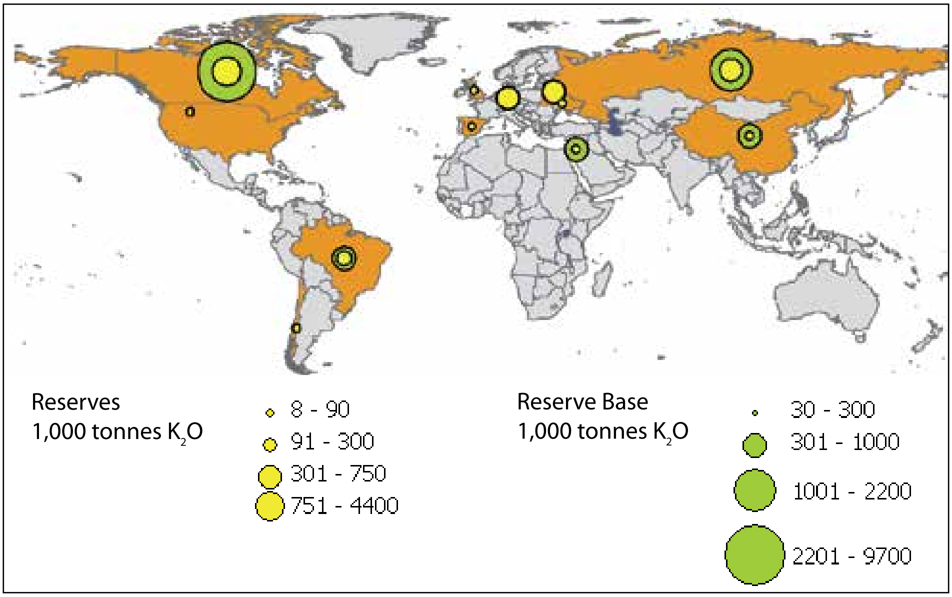

Figure 14.2 Locations of potassium deposits and size of reserves (Source: USGS, 2008).

and there is a need for exclusion of cadmium from phosphorus fertilisers to ensure safe food production. Based on a balance calculation, we calculated the maximum cadmium concentrations in fertilisers and amendments not leading to an increase of cadmium concentrations in soil.

Major potassium reserves that are economically feasible to mine include evaporated salt deposits from ancient inland seas, salt lakes and natural brines. According to US Geological Survey (2008), the largest deposits are found in Saskatchewan (Canada), Russia, Belarus and Germany, which together hold 92% of all reserves. The life-time of potassium reserves based on the current production rate is about 250 years for currently mined reserves and 500 years if the reserve base is included.

Sulphur is the 10th most common element on earth and many minerals occur as sulphides. Gypsum is a common sulphur-containing mineral, with thick and extensive deposits, but sulphur is also found as a pure element. Today, the demand for sulphur is covered from extraction of crude oil containing about 0.1-0.28% sulphur, from which it is obtained mainly as hydrogen sulphide byproduct. Global production of sulphur amounted to 48 million tons in 2009 (IFA, 2010). Only around 14% of the world's sulphur production is used as a plant nutrient (ammonium sulphate or superphosphate fertiliser). Large amounts of sulphur (more than 600 billion tons) are contained in coal, natural gas, crude oil and oil shale. Sulphur in gypsum and anhydrite is almost limitless (USGS, 2011). In other words, sulphur will not be a limited element for agriculture in the foreseeable future.

It must be borne in mind that assessments of the lifetime of nutrient resources are based on assumptions. In the estimates given above, it was assumed that current fertiliser use will remain constant over time. However, if increasing demand for fertiliser due to population growth is taken into consideration, the life-time of reserves will be shortened and the figures given are overestimates. On the other hand, if technical development allows nutrient recycling to be improved so that the majority of fertilizer use is based on recycled nutrients, the life-time of reserves will be prolonged.

14.6 Recycling of Plant Nutrients

All forms of agriculture remove plant nutrients from fields via the harvest of crops. The nutrients removed from fields flow through one or more of three cycles: the fodder cycle, the food cycle, and the industrial cycle (Figure14.3). The fodder cycle is the flow through housed animals, on or off the farm, which results in manures, slurries, urine, feed-lot wastes and deep-litter wastes. The food cycle concerns human consumption of food of plant or animal origin, and the resulting wastes. The industrial cycle concerns the industrial residues from processing of animal and vegetable food products.

In the past, the fodder cycle was more or less closed, since manures were normally recycled to arable land except for a proportion used for nitrate production for gunpowder. Today, however, transfer of fodder to a livestock farm can result in nutrient accumulation that far exceeds the absorption capacity of nearby farmland. Manure surpluses occur in many regions of Europe, Asia and the USA. For example, Haygarth et al. (1998) calculated that a typical intensive dairy farm of 57 ha in the UK with 129 lactating cows results in a net annual accumulation of approximately 26 kg phosphorus per hectare. On a national level, the Netherlands reported an estimated national surplus of about 8000 tons of phosphorus per year (Greaves et al., 1999). Incineration of manure to minimise the logistical difficulties of handling surplus manure and to recover energy is now practised in regions with a high animal density.

The food cycle suffers from severe problems regarding return of nutrients from cities back to arable land. Urban growth has resulted in centres of consumption, and hence accumulation of human wastes containing nutrients, that are far away from areas of agricultural production. Nutrients removed from the fields enter cities in the form of food of plant or animal origin, resulting in the production

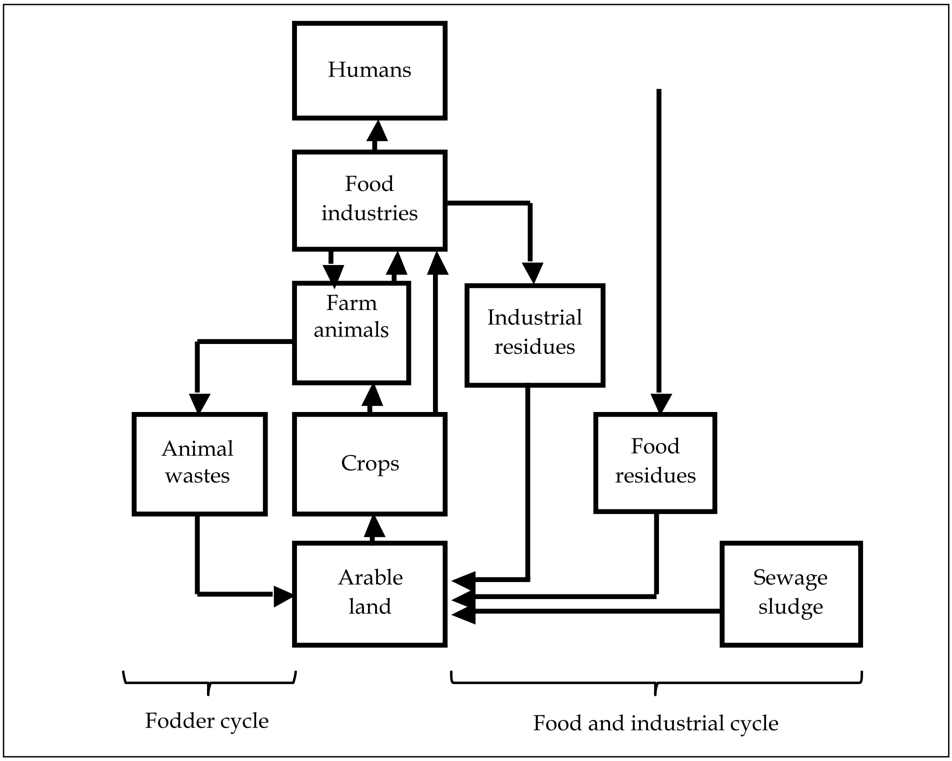

Figure 14.3 Plant nutrient cycling in society divided into fodder, food and industrial cycles. (Source: EHSA book 1)

of municipal wastes such as toilet waste in the form of sewage sludge, and organic household waste in the form of compost or biogas residues. The proportion of plant nutrients removed through harvest ending up in municipal waste amounts to about 25%, while the remaining 75% are present in animal manure (Kirchmann, 1998). Waste accumulation around cities leads to logistical difficulties in re-distributing human waste to arable land. Lack of available arable land for organic waste application within a reasonable distance from cities requires strategies and technologies for reducing the volume of urban wastes. In many cities sewage sludge is incinerated, whereby the volume can be reduced by approx. 90%.

An environmental target in modern societies is to recycle nutrients back to agricultural land in a sustainable way, which presupposes 'safe and clean' products. In order to achieve this target, a number of actions have already been taken. For example in EU countries, landfilling of organic material has been prohibited. The use of certain metals (e.g. cadmium, mercury) has been prohibited or is highly restricted to reduce contamination of wastes. Industries connected to sewage treatment plants must keep discharge of pollutants at a minimum to avoid contamination of sewage sludge. Source-separation of household wastes has been introduced to produce composts without contaminants. These efforts have improved the quality of municipal wastes. For example, the cadmium level in sewage sludge in Sweden has declined from rather high concentrations to only 20-40 mg per kg phosphorus (Eriksson, 2009).

However, it is questionable whether these commendable improvements will result in long-term use of municipal wastes on arable land, considering that a number of conditions must be fulfilled for sustainable recycling. These include (i) 'safe and clean' wastes that have a negligible effect on the soil and environment, (ii) high plant availability of nutrients in wastes to give a significant fertilizer effect, and (iii) redistribution of nutrients on arable land must be related to nutrient removal by crops (i.e. the 'law of nutrient replacement' should be followed).

Nutrients removed from soil through harvest and losses should be replenished with equivalent amounts. Application of excessive amounts to arable land is unacceptable and long-distance transportation would be required to achieve equitable redistribution while avoiding accumulation of nutrients in arable land surrounding cities. It seems that all these conditions can only be achieved if nutrients from organic wastes rather than whole wastes are recycled.

As toilet waste contains most of the nutrients present in municipal wastes, this fraction is most important to recycle. There are four main options available for recycling of nutrients in toilet wastes: a) spreading sewage sludge on arable land; b) separating human urine from faeces in special toilets and using the urine as a fertiliser; c) recovering phosphorus from sewage water in wastewater treatment plants; and d) recovering phosphorus from the ash of incinerated sewage sludge. Each option has advantages and disadvantages and the best choice depends on the conditions present.

There is currently a trend for more sewage sludge to be incinerated, not only in mega-cities but also in cities and towns, which means that spreading of sewage sludge will decrease in future. Ash may become the main waste product from increasing urbanisation. Processing of ash from combusted municipal wastes for nutrient extraction may be an important step to close nutrient cycling in society.

Assessments of global reserves for fertiliser production indicates that 'peak nutrients' in coming decades seem less likely. Still, over the long-term, recirculation of nutrients is the key to achieving more sustainable nutrient management. It should be remembered that the application of nitrogen, phosphorus and potassium fertilisers to agricultural soil over the last 100 years has increased nutrient

Conditions for sustainable recycling of plant nutrients
No adverse effect on food quality and the environment
Low levels of unwanted metals
Low levels of organic pollutants
Low levels of pharmaceuticals
Low levels of pathogens
Efficient nutrient supply
High plant availability
Low nutrient losses
Application according to crop demand
Equitable redistribution on arable land
Concentrated fertilisers enabling long-term transportation
Less energy demand for redistribution than production of mineral fertilisers

Table 14.1 Outline of conditions to achieve sustainable recirculation of nutrients. (Source EHSA book 1)

levels and improved soil fertility. However, in some parts of the world such as sub-Saharan Africa, arable soils are still nutrient-poor and there is a need to increase their nutrient status. It is necessary to increase the use of recycled instead of mined nutrients for fertilisation in future. This requires new approaches and technologies for handling municipal organic wastes. Only nutrients recovered from wastes, and not whole wastes, should be redistributed on arable land. This transformation is necessary in order to achieve efficient nutrient flows back from cities to remote arable land. In addition, recycled nutrients should have the same fertiliser value as mineral fertilisers, i.e., the same water solubility.

Chapter 14 sources:

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Section 14.3 Carbon flows in agricultural soils from Carbon Flows and Sustainable Agriculture by Thomas Kätterer in Ecosystem Health & Sustainable Agriculture, Book 1 of the Baltic University Program. http://www.balticuniv.uu.se/index.php/boll-online-library/817-ecosystem-health-a-sustainable-agriculture

Sections 14.4 Nutrient flows in agriculture – nitrogen, Section 14.5 Nutrient flows in agriculture – Phosphorus, potassium and sulphur and Section 14.6 Recycling of Plant Nutrients from Plant Nutrient Supply in Agriculture - Abundance Today and Shortage Tomorrow? By Holger Kirchmann, Yariv Cohen, Patrik Enfält and Christine Jakobsson in Ecosystem Health & Sustainable Agriculture, Book 1 of the Baltic University Program. http://www.balticuniv.uu.se/index.php/boll-online-library/817-ecosystem-health-a-sustainable-agriculture

Chapter 15
From waste to resource recycling and the circular economy

15.1 Waste management

In the 1970s countries in Europe became alarmed by rapidly growing piles of waste. Landfills were expanding in many countries both by household waste and waste from industries. This was propelled by non-recyclable products from bars, kitchens etc. as well as the increasing number of packages used for all kinds of products in the shops. More than 50% of household solid waste consisted of packages.

Even worse was (and is) the too common habit of illegal dumping of waste, e.g. along the roads, increasing with increasing costs of proper handling of waste. In addition to being ugly, it pollutes - sometimes seriously e.g. lead or mercury from old batteries - and threatens wildlife. A particular bad habit is to dump waste from ships right into the sea. The sea cannot accommodate all the waste from boats, and many times the waste turns into deadly traps for sea animals, such as seals. Especially plastic is serious since most of the plastic ever produced, non-degradable, is still there and pollutes. In the Pacific Ocean currents have concentrated plastic debris to a few large areas, the largest called the Trash Vortex.

In the European Union the amounts of household waste is, despite efforts over many years to decrease it, still increasing. In 2010 the total generation of waste in the EU-27 was 2 502 million tonnes; this was slightly higher than in 2008 but lower than in 2004 and 2006. It is now approaching 600 kg per year and capita. 45.4 % of the waste was disposed in landfills, or with mining waste in and around mining sites or discharges into water bodies. 49.0 % of the waste was sent to recovery operations. 5.6 % of the waste was sent for incineration (with or without energy recovery).

The costs of the growing piles of garbage and landfills mounted due to increasing land use and other resources being used up. Landfills were (and are) also environmentally problematic since they leak to groundwater and emit methane, a strong greeenhouse gas. During the last decade in EU the number of landfills has decreased and those remaining are strictly regulated and are subject to the IPPC Directive (Integrated Pollution Prevention and Control). Waste streams are man-

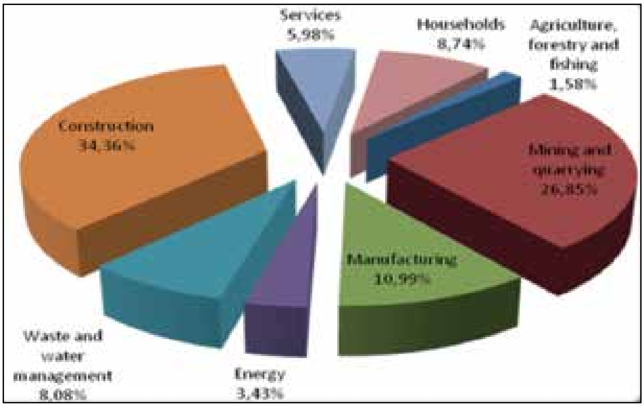


Figure 15.1 Share of waste generation by economic activities and households EU-27 2010.

aged according to increasingly more careful legal control. In an attempt to limit waste amounts waste sent to landfill are taxed.

An even more important aspect is that waste on landfills is a sign that the resource flow is linear, and therefore completely unsustainable and a symptom of badly designed production and consumption patterns. In general the material flows in Europe were in the 1990s overwhelmingly, more than 95%, linear and going from resources to production, to use and ended up as waste.

It is also clear that the waste stream includes a considerable amount of energy. This is particularly clear for metals: to produce a metal object from scrap metal rather than from the virgin ore is much less energy requiring. Thus to use scrap iron consumes 6 times less energy, scrap copper 30 times less and aluminium 50 times less energy compared to virgin ore. To use recycled paper instead of fibres from wood uses about 2.5 times less energy. It is obvious in all cases that virgin resources are saved, for example many trees in the case of paper production. Likewise waste to energy is important: Solid waste is incinerated and the heat used for district heating and coproduction of electricity; compostable waste is fermented to give biogas for energy purposes.

To develop a sustainable resource use pattern waste management has to be radically changed. This is on its way in a comprehensive waste strategy within e.g. the European Union. We talk here about the waste hierarchy, where "reduce" is the best and landfill is the worst. The top of the hierarchy reads

Reduce	the product flow, which leads to waste reduction
Reuse	the products, make products repairable, with longer lives
Recycle	materials in the products, and compost organic waste
Recover	the energy content in the waste, organic waste to biogas, waste incineration e.g. for district heating

Implementing the waste management hierarchy is an important component of sustainable resource management.

The largest waste categories are mining and industrial waste. Some strategies have developed to reduce these. A most sustainable option is industrial symbiosis. Here the waste from one industry is used as a resource in the next. For example the waste after enzyme production by fermenting with a yeast slurry was sent as a feed to a chicken farm. Heat from a refinery was used in the district heating in the nearby town. Sulphur in the flue gases was trapped in lime slurry in a wet scrubber and turned into calcium sulphate – gypsum – and sent to a factory for building-boards. Other examples include solid waste, e.g. ashes, used for building roads, while agricultural waste, e.g. animal manure is used in fermentation to produce biogas for energy purposes.

Construction waste is a special case since it is such a large waste category. Costs of waste have spurred building companies to be more inventive to reduce this waste category considerably. Waste is a resource! It is only in the wrong place.

The more systematic use of waste as a resource relies on the so-called industrial symbiosis concept. Here all outputs from an industrial process are used in the next production process in a system of industrial plants. Fully developed examples of industrial symbiosis are not common. The best know case may be the Danish Kalundborg (See box 15.1), but cases exits in many parts of the world. Most of them are in the agricultural sector where it seems to be easier to use waste, since it is organic material. This systems approach to production has been developed extensively by the Zero Emissions Research & Initiatives (ZERI). Here it is the careful use of all resources in a system that is in focus. The long-term goal is to achieve the zero-waste plant. Here nothing is wasted. Everything is used for some purpose. The zero waste concept has been developed in practice e.g. by Zero Emissions Research at Graz University of Technology in Austria. Here the cleaner production approach has been in focus.

15.2 Recycling strategies

A most important way to deal with waste is recycling. This means either to recycle the products themselves or the material they consist of. Most re-cycling involves converting or extracting useful materials from a product and creating a different product or material. Down-cycling involves converting materials and products into new materials of lesser quality. Up-cycling is the process of converting waste materials or useless products into new materials or products of better quality or for better environmental value.

Box 15.1 Industrial Ecology

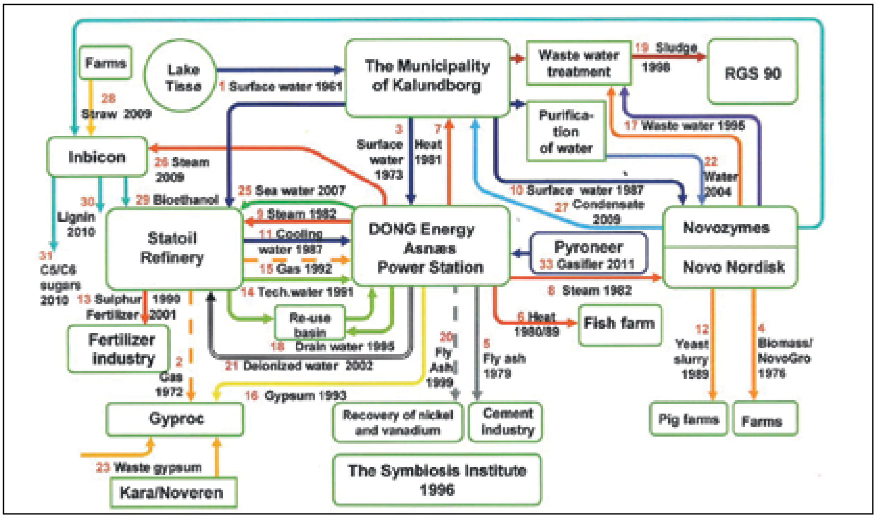
Industrial Symbiosis mimics the natural ecosystem by setting up a system of recirculation of residual materials from industrial processes or discarded products from consumer matter.

Industrial Symbiosis attempts to optimise the industrial system as a whole, rather than a particular process or subsystem, to increase the efficient use of a material. In fact, a larger, more complex, more diverse system may offer greater opportunities for efficient use and reuse of materials.

Industrial Symbiosis typically is pursued in a limited area, in a municipality or industrial area in a municipality. Cases are not very common but are found in several countries, in the far East, in Canada in Europe in e.g. Denmark and Sweden. An example of optimisation, which may be reached also in a larger scale, is illustrated by the Industrial Symbiosis cooperation between a number of industries in Kalundborg, Denmark.

Kalundborg Municipality, together with a power plant, an oil refinery, a gypsum board manufacturing plant, a pharmaceuticals plant, a biotechnical plant for production of enzymes, a plant for remediation of polluted soil, a waste handling company and a fish farm and the surrounding farming community benefit from joint utilisation of material residue that otherwise would end up as waste.

The description below is divided between cycles of energy, nutrients, inorganic waste etc. One needs to remember however that truly integrated systems rely on these flows being coupled, as they are in the body metabolism. Water is a carrier of material and energy, waste is a carrier of energy, etc. Many municipalities have established their own symbiotic strategies. Examples include the use of energy in waste for incineration, nutrients in sludge to improve soil in parks, and the energy from wastewater streams by heat pumps.



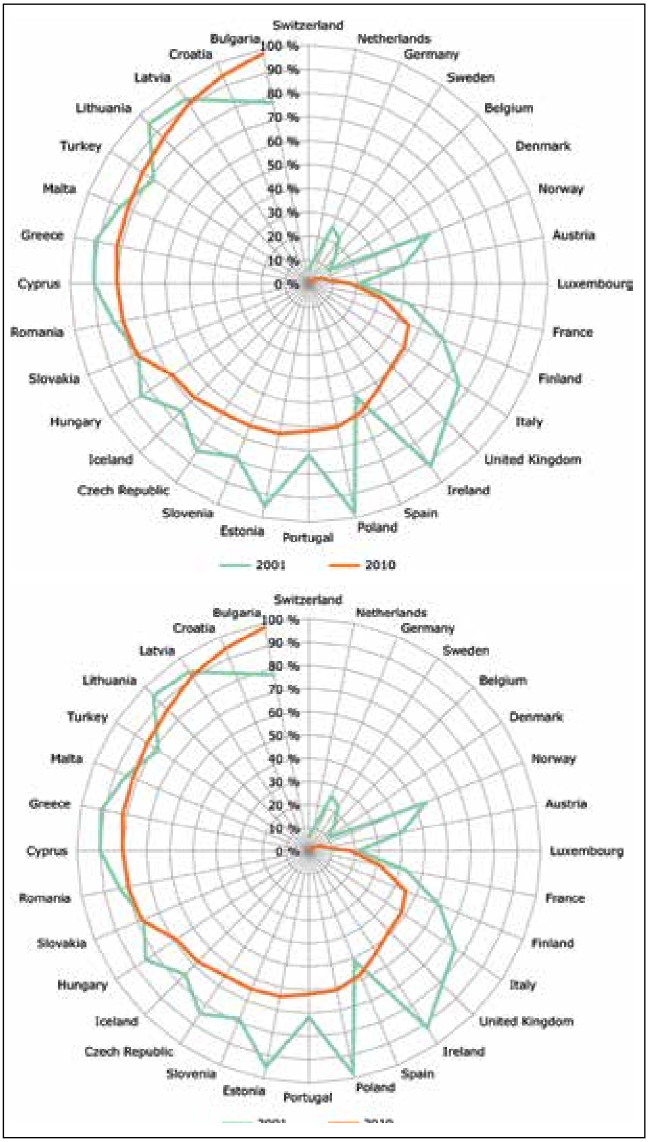


Figure 15.2 Waste management in 32 European countries in 2001 and 2010. Top Municipal waste landfilling rates; Bottom Material recycling as a percentage of municipal waste generation. (Source http://www.eea.europa.eu/data-and-maps/figures/municipal-waste-landfilling-rates-in ; http://www.eea.europa.eu/data-and-maps/figures/material-recycling-as-a-percentage

Recycling may be either internal or external. Internal recycling is when in a factory the material discarded in a product step is taken care of and, often after some kind of processing, fed back into the production chain. This is a very important part of Cleaner Production strategies and has reduced waste from industries and increased efficiency considerably. Internal recycling includes

Figure 15.3 External recycling of plastics, paper, glass and scrap metal is well established

- re-utilization of materials (solvents often after cleaning or distillation)
- reuse of materials for a different purpose (paper, solvents for inferior use i.e. pre-cleaning)
- closing of loops (process water often with a cleaning step)
- multi way systems (packaging materials)
- reclaiming of materials with high value

External recycling, or open loop recycling, is when the material is coming back to the production chain after having been used. A typical case is paper, which is sent back from the consumers after e.g. the newspaper has been used and read. The old paper is then washed to take away ink from printing and used for new paper products. Theoretically a cellulosic fibre can be recycled some 6 times before it is too short to be useable for paper. Then it is sent to incineration. This process is also a case of down-cycling, as the quality of the material decreases at each cycle.

Recycling is never perfect but in some cases they may be close to 100%. Thus recycling of lead-containing car batteries is very well organized in some countries to make such a technical recycling loop close enough to perfect to allow the use of the quite toxic lead in society. We would like to see the equally perfect recycling of all kinds of batteries but this is not yet the case.

Recycling of household waste ask for a good waste sorting already in the households themselves. Good household sorting gives 6 basic fractions (compostable, burnable, paper and cardboard, plastics, metal, glass). Of course this has to be followed by proper processing at the later stages, which is not always in place. In addition special waste, such as batteries, light bulbs etc has to be managed in addition to the six categories mentioned.

The many toxic components in different kinds of ordinary household equipment have prompted the European Union and other countries to introduce strict legal requirements on waste management of many products. Best known may be the Waste Electrical and Electronic Equipment, WEE, Directive. This prescribes how to properly take care of all kinds of electrical and electronic equipment, such as computers, refrigerators etc. It puts large responsibilities on the local or regional authorities most often the municipalities. This is however only a small part of the whole. The European strategy for prevention and recycling of waste is one of the presently seven environmental themes in the EU and is backed by the Waste Framework Directive, which includes a long list of special directives.

Recycling is also backed up by economic incentives, most importantly the deposit and refunding system. In this system the customer when buying a beverage pays an amount of money for the bottle or can. He/she is then refunded when the empty bottle or can is returned. In this way more than 90% of aluminium cans in Sweden are recycled.

Increasingly often the producers are also legally required to take care of the wasted products. This is called Extended Producer Responsibility, EPR. In many countries it applies to a large number of electric and electronic products, large equipment such as cars, and equipment with some toxicity, e.g. light bulbs.

Some waste can be bought and sold, that is, it has a market value. Thus scrap metal is quite valuable on the market, and sometimes scrap plastic is also sold. Quite expensive is scrap copper. Also some bio-waste is sold and bought, e.g. forest residues. More recently other products have entered the market, such as used car tires.

Of course any kind of used items (cars, furniture etc), which are offered on a second hand market belong to this category, and some municipalities make considerable efforts to make this second-hand market functional. In the waste hierarchy it belongs to reuse.

In order to make recycling practical products have to be designed to allow separation of the material they are made of. Earlier this was a problem with many items made of composite materials. Today this have improved very much. Even many cars can today be completely dismantled and all components in the car sent to recycling. Of course it is in the interest of the producer once take-back is legally required.

15.3 Long term metal use and recycling

The potential for recycling metals is very high. Metal atoms are not degraded during use and recycling. They can in principle be recirculated for ever. Instead metals may be successively degraded by impurities influencing their quality, which severely restricts their future use. In using metals we mix different metals with each other, either intentionally as in alloys or in, for example, recycling processes due to incomplete separation. Shredding car scrap tends to contaminate iron with copper which, even in small concentrations, reduces the applicability of recycled iron. In order to avoid mixing (degradation) it is important to have various metals as well as various alloys separated from each other, for example, through a 'design for recycling'. But it is also necessary to develop recovery and recycling processes. To make it possible to achieve high-quality recycled metals, it may be necessary to decrease the number of various alloys.

In the long term, the pool of metals so far accumulated in society and available in resources is large compared to nature and constitutes a future threat. The accumulation of most metals is also still going on. This pool tends to leave the technosphere sooner or later. The long-term question is what the acceptable final storage places for this pool are and how the metals can get there. Today, losses are predominantly to waste deposits. With more closed cycles the losses are smaller but a larger proportion of these losses may be less controlled. With closed cycles the question is also partly transferred to future generations.

The scarcity and interconnection of metal resources may restrict the future use of metals to specific high-value applications and influence the choice of technology and the expansion rate of various applications. This restriction can have important implications for strategic choices among possible future key technologies within, for example, energy conversion and storage. Policies involving reliance on large-scale introduction of technologies, with inherent intensive utilization of scarce metals as the means of solving specific environmental problems, can thus be questioned. For instance, this may apply to certain battery-powered electric cars as a substitute for vehicles using internal combustion engines. Metal resources are also of great importance for the possible expansion of various types of thin-film solar cells.

It is interesting to study copper because the societal flow of copper is very large compared to the natural flow. This means that there is a great risk of an increased concentration of copper in the environment. We can draw the following conclusions about the use of copper:

The intake of copper into the technosphere exceeds the outflow from production and consumption systems. This means that there is still a continuous accumulation of copper in society in, for example, buildings, infrastructure and consumer goods. There is also a large accumulation in various dumps, in tailings at mines and in deposits of production and consumption waste.

The diffuse and unintentional leakage from various products such as copper roofs and the tap-water system, exposed to wear and tear or corrosion, is of the same order of magnitude as emissions from industry. The flow due to the intentionally dissipative use of copper, such as in the use of copper-containing impregnating agents, is even greater than the unintentional flow from copper roofs and the tap-water system, etc. Consumption emissions are thus larger than production emissions.

The potential for recycling is large, not the least because of the high price of scrap copper. And the major amount of copper in used products dealt with by the waste-handling system is recycled. However, a considerable proportion is deposited in dumps and landfills.

For toxic metals, recycling is evidently very important. Lead is of particular interest. The lead budget in Sweden in 1989 amounted to about 35,000 tons in total. This corresponds to about 4 kg/capita which is close to the European average. Of this some 20,000 tons, or 60 per cent, were recycled; mainly car batteries. The rest, some 15,000 tons, was supplied from mines and lost from the system. Outlets to air and water, registered by local authorities, comprised about 500 tons. Lead deposits in landfills, not registered were however substantially more, about 3,000 tons.

This means that some 11,500 tons of lead were accumulated in the technosphere each year. An average figure for the last 100 years is 21,000 tons. Thus, in total, some 2 million tons of lead have been taken into the Swedish technosphere during the last 100 years. This amount gives rise to a calculated emission of some 1,750 tons per year. It is again far more than the 500 tons registered by local authorities.

We can get a rough understanding of the size of these flows by comparing them to various measures of natural turnover. Weathering amounts to some 500 tons of lead per year, while leaching from Swedish agricultural soil has been estimated at 23 tons/year.

A special study was conducted on the losses of lead in the production and recycling of car batteries. The total turnover of lead in this recycling system amounts to 20,000 tons per year. The loss of lead from the system depends on the recovery rate. With recycling rates up to 99.97 per cent, the predominant lead losses occur in the use and recovery of batteries. If the recycling rate is greater with lead going into by-products, losses to air and water, etc. will dominate with some 10 tons per year. This unavoidable outflow, about 0.5 promille, is several orders of magnitude less than the loss from the lead system as a whole.

The recovery rates discussed here, 99 per cent or more, will give us a residence time of lead in the system far beyond our present planning horizons. These are 400 years for 99 per cent and 9000 years for 99.9 per cent recovery. This raises the question of how to handle the lead when it is taken out of circulation, for example, because of new technologies. Similar questions are already being dealt with in respect of radioactive waste and plutonium, and is now being implemented for mercury which is slowly taken out of use. It is increasingly restricted use in dentistry and more importantly in chlorine-alkali industry. At present in Sweden these metals are deposited in safe storage in deep mountain stores.

15.4 Emissions of metals reduces recycling

Recycling of metals is counteracted by losses from emissions. Emissions of metals to the en-vironment can occur all along the chain from the cradle to the grave. Emissions from the pro-duction system have historically increased with increased production during industrialization. Fortunately, the environmental restrictions introduced in later years have drastically reduced these point emissions to water and air from the production system. Instead, today, major emissions of metals to the environment in modern industrial systems tend to emanate from the consumption phase of the goods and not from their production, which can be illustrated by the estimated emissions from the historical turnover of chromium and lead in Sweden (Fig. 15.4). This is also true for the copper flow.

There is a huge range in consumption losses between various types of use. We have uses of metals that are intrinsically dissipative in their character. In chemical uses especially, metals are spread intentionally either already as products or in their uses as in, for example, paints and biocides. However, there are also intentional losses involved in metal uses, such as the lead used in ammunition. Losses from wear and tear or corrosion of products also vary considerably. For example, use

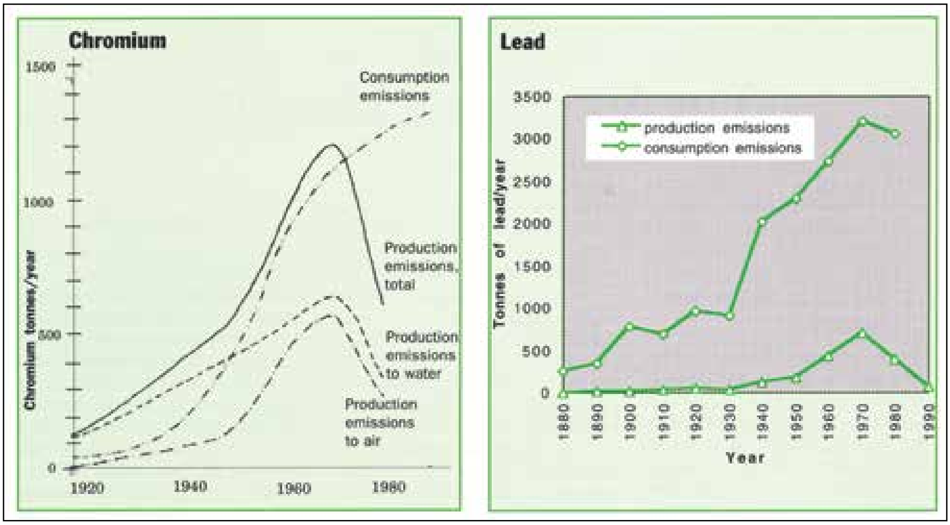


Figure 15.4 Metal emissions. Left) Emission of chromium from the production and the consumption of goods containing chromium, inclusive of emissions from incineration and leakage from waste deposits. Sweden 1920-1980. Right) Emission of lead from the production and the consumption of goods containing lead. (Karlsson, 1996).

of copper that give rise to emissions include, copper used outdoors and exposed to weathering as in roofing and facing materials, copper exposed to liquid flows as in tap-water systems and heat exchangers and copper in braking pads.

The dissipation of the metals are concentrated to the places where the metals are used, that is mainly in towns and villages and where our industry and infrastructure are located. Locally the emissions to soil and water can be very high However, for metals, the major system losses tend to emanate, not from direct emission to the ecosphere, but from lack of recycling. System losses mean metals in the techno-sphere that are taken out of use but are then are not recycled such as flows to deposits through waste-handling or materials simply left behind when no longer in service. The copper flow illustrates this. Large flows of copper recovered by the waste-handling system are not recycled, but are ultimately deposited in land-fills. A lot of copper in cables laid down in the ground, for example, is not recovered when the cables are taken out of service.

When recovered metal is of suitable quality, today's production technology often makes it possible to keep a very closed metal system, which can be exemplified by the lead system. This is also underscored by the fact that secondary production of metals often has much less specific loss than the corresponding primary production.

In Sweden, according to a Government Bill passed in Parliament in 1991, the use of mercury, cadmium and lead is to be restricted and, in the long run, phased out completely from the technosphere. But is this situation of these metals not being used at all the only long-term option for their sustainable use? Could we instead have metals in certain uses in a sufficiently closed system within the technosphere? It seems reasonable that any phase-out should depend on the toxicity of the metal. But, for example, should very toxic elements be substituted for whatever the use and is it reasonable to have a non-restricted use of non-toxic metals whatever the character of the use?

In the short term, to avoid direct emissions, a metals policy focusing on consumption with large inherent dissipative losses of metals, which are environmentally harmful or have large flows compared to natural turnover, can thus be efficient to decrease hazardous emissions. The efficiency of various counteractions will depend very much on the function of the dissipating metal and the rôle of consumption in each specific case. The metal may not be the main flow nor even incorporated in the final product. Lead in petrol is a good example. There may be competitive technological options available, fulfilling the services required, as with various materials options for roofing and piping. Generally, development or use of technological options for substitution at various levels should be more efficient than dematerialization of the main flow or simply avoiding or lowering the use.

If we want to close the loops within the technosphere, it is important to know how closed the system can be and which parameters are the dominating factors. For instance, in the lead-acid battery system, the production system has the potential for fairly low losses (compared to, for example, natural flows) and the recovery of the batteries after use is a very important factor. The answer is crucial because lead is considered to be one of the metals that most threatens human health; it is non-essential to biota and the anthropogenic mobilization of lead from the lithosphere is much larger than the corresponding natural flow. We can argue that if it is possible to have large-scale use compatible with long-term environmental and health requirements, we may not have to choose a complete phase-out policy, but instead can regulate specific uses. The policy of directing effort towards the use of the metal rather than the metal itself may serve as a pattern for the sustainable use of other metals as well.

15.5 Recycling special and scarce metals

Approximately 30 metallic elements are made commonly available in society through mining and processing of their ores. Many metallic elements are used in

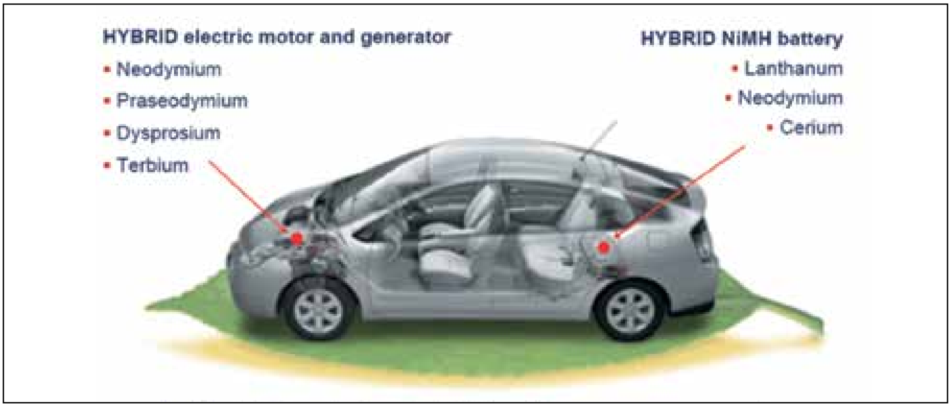


Figure 15.5 Rare Earth metals are used in a number of special electronic applications, e.g. in hybrid electric cars, in wind power turbines and in other electronics. Most of these are today mined only in China. The recycling of these elements are still to be made much more efficient In the European Union only few companies have the capacity and competence to extract and recycle these metals from scrap equipment such as computers and mobile telephones. (Source: http://www.australianrareearths.com/current-issues.html)

their pure forms, however, because of their unique properties. Chemical mixtures (alloys) of two or more metals, or metals and non-metals, often have superior properties of corrosion resistance, durability or strength.

Iron totally dominates societal use of metals. Compared to other materials flows in society, the flows of metals, except for iron, are relatively small. But metals are technically and economically very important to industrialized society and this is reflected in their relatively high prices. Many other metals are closely linked to the use of iron as ferro-alloy metals. Partly because of their relatively low weight, society uses an increasing amount of the abundant light metals, especially aluminium, but also titanium and magnesium.

Society still also uses a lot of the traditional non-ferrous metals or base metals, for example, copper, lead, zinc, tin and mercury.

The precious metals of antiquity, gold and silver, were called noble metals. Today the so-called platinum group elements are also called precious or noble metals because they too exhibit non-reactive properties.

Finally, there is a group of metals, the special metals, which do not fit into the categories mentioned above. These metals have unusual properties that make them important in industry. Tantalum, for example, is widely used in electronics because of its special properties.

Many metals are scarce but valuable and are therefore extracted from ore of a low grade. Despite the relatively low volume of extracted useful metals, some metals contribute extensively to the ecological rucksack. Iron, because of the large volume used in society, and copper, because of its low-grade ores, give rise to huge amounts of discarded useless materials in mining and concentrating operations and also in subsequent metallurgical processes.

The extraction of five grams of gold (about the amount in a wedding ring) needs the excavation of around one cubic meter of lithospheric materials The rucksacks consist mainly of large dumps and translocations of materials at the mine and may give rise to mainly local effects. They are therefore probably of minor importance from the perspective of sustainable development. If mining is done in agricultural areas, it can imply serious problems for these areas. Leakage of metals from mines and overburden can also imply long-term effects on the local environment.

Potentially extractable metal ore deposits are suffering from various degrees of scarcity. Extraction is coupled to extensive manipulation and the intensive and often dissipative use of metals has led to severe contamination of the environment and threats to human health.

One important observation is that certain metals that are scarce in nature are not scarce in society. The relatively large use of many of the scarce heavy metals compared to natural turnover has an important implication: societal use of these metals has a large potential for producing substantially increased concentrations of them in the ecosphere. Limited assimilative capacity in natural systems sets restrictions on the uncontrolled emissions of these metals. Contamination by heavy metals has also been a serious environmental problem so far during industrialization. The light metals are in a better position in that their societal use is small compared to natural turnover.

Metals can be separated in two main groups, abundant and scarce, on the basis of their abundance in the Earth's crust. The abundant metals are those that individually make up at least or almost 0.1 per cent by weight of the Earth's crust. There are very few such metals: iron and the light metals aluminium, magnesium and titanium and then, at almost 0.1 per cent, manganese. All other metals occur in much lower concentrations, near to 0.01 per cent and less, and are categorized as geochemically scarce metals.

The abundant metals are available in increasing amounts in lower grade down to the com-mon rock, from which they can be mined directly. It is argued therefore, that society will never experience a sudden scarcity of these.

All metals are mined from ores rich in specific separate minerals containing metals. The ores are ground and the metal-bearing minerals are separated and concentrated before metal-lurgical treatment in which the metals are extracted from the minerals. In the Earth's crust, however, the scarce metals are very seldom concentrated in separate minerals, but most often are found, in small concentrations, stochastically distributed as substitutes for other elements in the minerals of ordinary rock. It is not possible to grind these minerals to separate specific atoms or molecules. Instead the metallurgical process has to treat all of the ordinary rock, which make the metal practically unavailable. This has been called the 'mineralogical barrier'. It has been estimated that not more than one in 104 to 105 of the total amount of each metal is located in a separate mineral. This can give a rough estimate of the ultimately re-coverable amounts.

15.6 Recycling of macronutrients

Recycling of macronutrients should finally be briefly mentioned. This topic is treated more fully in chapter 14. Industrialised agriculture largely depends on linear material flows of nitrogen and phosphorus. This is unsustainable. Phosphorus, mined from a few deposits in the world, will as a non-renewable resource finally become emptied. Nitrogen produced by the industrial fixation of nitrogen gas requires large input of fossil energy and is thus also in this way non-renewable. The industrial nitrogen fixation is of the same order as the biological one and nitrogen flow has thus doubled. Excess nitrogen and phosphorus from agriculture is today polluting the water in lakes, coasts and the sea in many parts of the world, and it is causing serious eutrophication.

Implementing recycling of macronutrients is thus a key concern. Among the many efforts made today to re-establish circular flows of nutrients we see how manure, directly or as a residue after biogas production containing most nutrients, are being returned to fields; food waste in cities is collected; and sludge from wastewater treatment plants is used for fertilisation. But it is insufficient and heavy metals and toxic organic chemicals too often pollute organic waste, e.g. sludge from wastewater treatment plants.

Phosphorous does not have a gaseous form and thus stays on land and in water. In industrialised countries sludge from wastewater treatment plants is the largest source of phosphorus. If this can be returned to agriculture a main step in the recycling of phosphorus would be taken. This phosphorus comes from human excrement as well as everything with phosphorus, such as detergents and food residues.

Recycling of nitrogen is more complicated since nitrogen is found in so many places, products and contexts. Biologically nitrogen is returned to atmosphere as nitrogen gas after bacterial denitrification in conditions where oxygen is limited, as in not too vivid streams and in the soil. However this natural recycling is not

Figure 15.6 Ellen MacArthur is best known as a solo long-distance yachtswoman. On 7 February 2005 she broke the world record for the fastest solo circumnavigation of the globe, a feat which gained her international renown. Following her retirement from professional sailing on 2 September 2010, MacArthur announced the launch of the Ellen MacArthur Foundation, a charity that works with business and education to accelerate the transition to a circular economy. Photo by Laura Kidd. (Source: http://en.wikipedia.org/wiki/Ellen_MacArthur#)

at all sufficient to keep a healthy level of nitrogen in waters receiving not fully cleaned wastewater or run off from agricultural fields.

Measures to take include to improve removal of nitrogen from wastewater in treatment plants or reduce nitrogen in runoff by the same methods as for phosphorus, such as in buffer zones or in wetlands including small streams. In fermentation of manure or in general organic waste most of the nitrogen in the substrates remain in the solid residue and contributes to making this an excellent fertiliser.

15.7 The circular economy

The circular economy is a generic term for an industrial economy that is, by design or intention, restorative and where recycling is a main strategy. The materials flows in a circular economy have two types of material: biological nutrients, designed to re-enter the biosphere safely, and technical nutrients, which are designed to circulate at high quality without entering the biosphere. The circular economy builds on four principles.

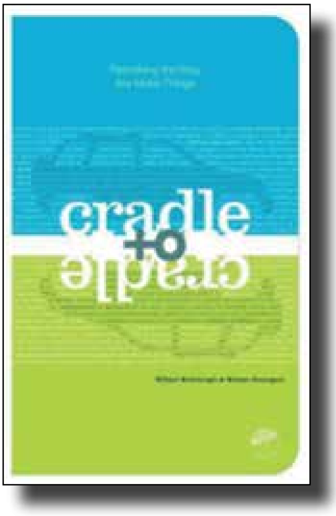


Figure 15.7 Cradle to Cradle Products Innovation Institute Developed by Michael Braungart , Hamburg and William McDonough, San Fransisco (Source: http://www.mcdonough.com/cradle_to_cradle.htm)

- Waste is Food - The biological nutrients are non-toxic and can simply be composted. Technical nutrients are man-made materials designed to be used again.
- Diversity is strength - Diverse systems, with many connections and scales are more resilient in the face of external shocks, than systems built simply for efficiency.
- Energy must come from renewable sources - As in life, any system should ultimately aim to run on 'current sunshine' and generate energy through renewable sources.
- Systems thinking - The ability to understand how things influence one another within a whole infrastructure, environment and social context usually non-linear systems.

The idea of establishing a circular economy has today a rapidly increasing support. Thus in 2012, the European Commission published a document entitled Manifesto for a Resource Efficient Europe. It says "In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy."

A well-known promoter of the circular economy is Ellen MacArthur, best known as a solo long-distance yachtswoman. On 7 February 2005 she broke the world record for the fastest solo circumnavigation of the globe, a feat which made her international renown. Following her retirement from professional sailing in 2010, MacArthur announced the launch of the Ellen MacArthur Foundation, a charity that works with business and education to accelerate the transition to a circular economy. Ellen MacArthur Foundation is today working with major business to develop strategies for a circular economy.

Michael Braungart, Hamburg and William McDonough, San Fransisco have in their Cradle to Cradle Products Innovation Institute made the circular economy practical. Again they stress that in Cradle-to-Cradle, often called simply C2C, all materials used in industrial or commercial processes fall into one of two categories: "technical" or "biological" nutrients. Technical nutrients are strictly limited to non-toxic, non-harmful synthetic materials that have no negative effects on the natural environment; they can be used in continuous cycles as the same product without losing their integrity or quality instead of being "downcycled" into lesser products, ultimately becoming waste. Biological Nutrients are organic materials that, once used, can be disposed of in any natural environment and decompose into the soil, providing food for small life forms without affecting the natural environment.

The C2C Institute have certified companies working according to their requirements and presently there are many hundred companies certified.

15.8 Business models in the circular economy

The growth model favoured by economies and indeed most companies for the past 250 years - based on the availability of plentiful and inexpensive natural resources - is living on borrowed time and so are companies that rely on it. A body of research and experience tells us that when resources are abundant and inexpensive (and the impact on the environment is not a prevailing concern) the current "linear" approach to satisfying demand can be very successful.

Companies are able, with ever-increasing efficiency, to extract raw materials, use those materials as inputs to the manufacturing of desired products, and sell and ship those products to as many customers as possible (who use and discard them after the products have served their purpose). Put in shorthand, this is an economy built on the principles of 'take, make, waste'.

However, we are rapidly approaching a point at which the linear model is no longer viable: when, due to rising global affluence, the availability of many non-renewables (including metals, minerals, and fossil fuel) cannot keep up with demand, and the regenerative capacity of renewables (such as land, forests, water) becomes strained to its limits.

For businesses and their top executives this leads to one inescapable conclusion: Continued dependence on scarce natural resources for growth exposes a company's value to serious risks. Supply uncertainties and cost increases are future risks and so is the potential for an eroding brand value as consumers shun companies with unsustainable business practices.

In a circular economy business models will rely on longevity, renewability, reuse, repair, upgrade, refurbishment, capacity sharing, and dematerialization. Companies concentrate on rethinking products and services from the bottom up to prepare for inevitable resource constraints. This implies eliminating waste, creating step changes in resource productivity.

Circular economy business models require companies to become highly involved in the use and disposal of products, finding ways to move from selling the physical stuff to providing access to it and/or optimizing its performance along the entire value chain. Take a conventional power drill as a telling case. A power drill is typically used for less than 20 minutes during its life cycle and while customers need a hole in the wall – the market supplies millions of tools collecting dust most of the time. If, instead, users had convenient access to a high-quality tool only when needed, they could save money and time while the product could be optimized for longevity, component reuse, recycling,

Many companies across the globe have already adopted circular principles to close the loop on energy and material. Prevailing philosophies behind the used business models include economy of sharing, exemplified by e.g. car pools or second hand business; selling services rather than products, exemplified by e.g. car leasing and manufacturing using recycled material. These business models have their own distinct characteristics and can be used singly or in combination to help companies achieve massive resource productivity gains. Accenture, a global major consultancy to business promotes the following business models to their customers.

Circular Supplies is based on supplying fully renewable, recyclable, or biodegradable resource inputs that underpin circular production and consumption systems. This model is most powerful for companies dealing with scarce commodities or ones with a major environmental footprint.

Resource Recovery of embedded value at the end of one product lifecycle to feed into another promotes return chains and transforms waste into value through innovative recycling and upcycling services. This model has its bedrock in traditional recycling markets. Solutions range from industrial symbiosis to integrated closed loops recycling and Cradle-to-Cradle® designs where disposed products can be reprocessed into new. It is a good fit for companies that produce large volumes of by-product or where waste material from products can be reclaimed and reprocessed cost-effectively.

An example of a company that is recovering residual value potential in post-consumer product waste is carpet manufacturer, Desso. The company developed a separation technique called Refinity®, which enables separation of yarn and other fibers from carpet backing. After a purification stage, this allows the yarn to be returned for the production of new yarn in a Cradle-to-Cradle® system.

Product Life Extension allows companies to extend the lifecycle of products and assets. Values that would otherwise be lost through wasted materials are instead maintained or even improved by repairing, upgrading, remanufacturing or remarketing products, for instance, an outdated component is replaced instead of the entire product.

Sharing Platforms promotes a platform for collaboration among product users, either individuals or organizations. These facilitate the sharing of overcapacity or underutilization, increasing productivity and user value creation. This model, which helps maximize utilization, could benefit companies whose products and assets have a low utilization or ownership rate.

The Product as a Service business model provides an alternative to the traditional model of "buy and own." Products are used by one or many customers through a lease or pay-for-use arrangement. This business model turns incentives for product durability and upgradability upside down, shifting them from volume to performance. This model would be attractive to companies whose products' cost of operation share is high and that have a skill advantage relative to their customers in managing maintenance of products (giving them an edge in selling services and recapturing residual value at end of life).

Michelin, one of the world's leading tire manufacturers, has created an innovative program in which fleet customers can lease instead of purchase tires. Michelin effectively sells "tires as a service" and customers pay per miles driven. They don't own the tires and don't have to deal with the hassles of punctures or maintenance of any kind.

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Book 3 Sten Karlsson Chapter 7 The valuable metals

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http://www.accenture.com/us-en/Pages/service-circular-economy-innovation-video.aspx

Chapter 16
Policy instruments for resource management

16.1 Resources as an economic good

Since resources are economic goods there are many efforts to control the flow of resources in the market and in the economy. Resources are sold and bought and thus are subjected to taxation, regulation and …. The main question in this final chapter is if these mechanisms are enough to establish a sustainable use of resources and if so which conditions should apply.

Are the price of a resource high enough to make its use limited and its recirculation in the economy profitable? A main part of the price of a resource is the environmental impact caused by its extraction and use. These are too often not included in the price and thus remains as so-called externalities. Ecological economics requires that the externalities are internalised into the price and thereby a first step is taken to make the resource flow more sustainable. A basic requirement is the polluter pays principle, PPP. If this is implemented it will cause an internalisation of the externalities.

A sign of the values of a resource is how it is recycled. If it has market value it is a first step towards a more sustainable resource management as it will stay in the techno-sphere and not become waste. Today almost all metals have value as scrap metals, which promote their recycling. If the price of virgin metal includes externalities it is even better as the recycled metal will be more competitive.

The price is important for the behaviour of the consumer. In the former communist system natural resources such as water or energy had no or almost no costs. In connection with transition to a market economy in the Central and Eastern Europe these resources were given a price. An immediate effect was the much more careful management of water and energy in the households and other consumers. Thus in Gdansk in Poland the water consumption in the 1980s was almost 600 lit/cap and day and increasing. When water consumption had to be paid the consumption dropped greatly. The extraction of surface water could decrease and the quality of water improved. As the price slowly increased consumption dropped to just below 100 lit/cap and day. Very many leaking toilets and faucets were taken care of during this process! A similar story can be told about energy use.

16.2 Regulation

To keep the environmental impact of industrial activity within politically acceptable limits industrial processes are regulated by authorities, based on national and international law,. The regulation consists of *normative*, or command-and-control, instruments as well as *economic* – market driven – instruments.

Normative regulation focus on the consequences of industrial discharges into the air and waters. Regulatory legislation has today an integrated approach. The integrated approach is to secure that the operator of a firm is discouraged from transferring pollution from one medium to the other. Although regulation by tradition focus on environmental impacts also resource use are covered by the regulations. Typically use of water and energy are regulated by integrated permits.

Environmental regulations were traditionally differentiated according to type and absorbing capacity of ambient nature. Companies were required to decrease or clean the discharges to meet the limits established against this background. The integrated approach contributed to shifting the focus from "end-of-the-pipe" to the source of the pollution, i.e. to the production process. This meant a shift from a predominantly static and defensive to a dynamic and proactive approach to regulating industrial environmental activity. In the EU-member states this led to demands on technology and tighter emission limit values. It was formulated in the 1996 Directive on Integrated Pollution Prevention and Control, the so-called IPPC directive. This directive required industrial installations to use the Best Available Techniques (BAT) and base its emission limits as well as resource use upon this assumption.

The environmental regulatory framework in the EU, and in most industrialized countries, requires that companies attend to the *law*, and respect the *standards* for the use of technologies. Industries have to receive *licences or permits* to allow them to operate. The licence is implementing the law. *Monitoring* is the follow-up check from the environmental authorities of every single operation to make sure that the licence – and thereby the law – is complied with. When non-compliance is registered, an *enforcement*, is activated. That may in the end mean substantial fines for the company and for management personally and, possibly, closure of the company and its operations.

In addition to national and European regulations there are also regulations based on international law. These are the treaties or conventions made regionally or globally (e.g. the Climate Convention). These enter into force in the individual countries only after ratification (confirmation) by the national parliament.

All nations have authorised some institution to control the activities and thereby implement the regulations. These are referred to in the legal text as the

Competent Authority (CA). For small installations it is often a municipality-based authority or a regional, that is, a county-based, authority. For larger installations it is typically a national authority such as the Environmental Protection Agency of the country, but it may also be e.g. an Inspectorate, such as the Chemical Inspectorate.

A considerable part of the environmental impact in our countries is caused by industrial activities. In the European Union there are millions of companies of concern for the environment and thus in need of regulation for the protection of the environment. The large majority of these are small and medium sized enterprises, SMEs, mostly with a limited impact. These are all controlled by national legislation. But there are about 50,000 large industrial sites with activities of major concern. These are all controlled by the IPPC Directive and should have an Environmental Licence based on this directive to be allowed to operate.

The IPPC Directive is, as mentioned, concerned with the major industrial installations and installations in sectors of industry with potentially high environmental impact or risk. These include among others: energy industry; production and processing of metals; mineral industry; tanning; chemical industry and waste management. It means that most private industrial output is regulated by the directive. The smaller and/or less dangerous installations are typically regulated along the same lines, but according to nationally established regulation.

The regulatory concept in the IPPC-directive is that the industrial activities, included in the Annex 1 to the directive are prohibited, i.e. cannot be established and commence activity, until they have been given an environmental licence. The licence includes specification of the regulatory requirements they should fulfil to be allowed to operate. This concept makes sure, that risks are controlled from the very start. And, even more importantly, the environmental authorities are not met with a *de facto* situation in terms of big investments, which are difficult to have modified or changed dramatically for environmental protection reasons when first established.

The directive represents a new approach in European industrial regulation. The integrated licence, comprising all media (air, water and soil) and all outputs (polluted air/dust/gases, wastewater and solid waste) is the instrument developed to put this approach into practice. It addresses all relevant aspects of environmental impact from an installation. Earlier, emissions to air and water were considered separately in accordance with two different Directives. The IPPC directive furthermore emphasizes that attention must be given first to prevent the generation of the pollution, and only when this is not possible action must be taken to reduce emissions by means of cleaning technologies.

The overall purpose of the directive is to ensure that member states of the Union provide the necessary framework for the Competent Authority to be able to ensure that installations are run in a proper way. The Competent Authority, most often the Environmental Protection Agency, EPA, should thus see that the necessary measures are taken in order to prevent pollution, particularly through the application of BAT. Waste production is avoided or that waste is recovered when produced and – if it is technically and economically impossible – is disposed of while avoiding or reducing any impact on the environment and energy is used efficiently.

16.3 Economic instruments

Economic instruments are applied to change behaviour by economic incentives. But why do these incentives need to be imposed? Why do not companies and individuals see and go for these benefits on their own?

There are several reasons. First a good deal of the natural environment, such as the air, is "common good", i.e. it has no owner. There is then a risk of exploitation. The state comes in to play the role of the owner to protect this common good. It may do this by charging a fee for its use.

In other cases there is no possibility of charging for the use of a service, for example street lighting. But it costs something to provide it. In order to cover the costs again the public has to collect a tax.

Thirdly, and more importantly, environmental consequences of human activities are diffuse, wide-ranging, piece-meal and often dangerous only in the long term. A few examples may illustrate this:

Particles from car exhaust in the city affect health seriously; people exposed to particles on the street will bear the consequences, far away from the car owners.

Nutrients and pesticides leaking from agricultural land cause pollution of rivers and coastal waters; reduced water quality, reduced biodiversity etc will be felt far away from the polluter.

Pollution of air by SO_X and NO_X cause degradation of buildings, monuments and corrosion of various installations due to acidification; owners of these monuments or equipments are far away from those emitting the acidifying gases.

Release of CO_2 from power generation etc., create the enhanced green house effect; those suffering from the consequential climate change are often far away from the polluters.

Some of these impacts are regulated by regulatory policy instruments. Emission values, imposed by the environmental licences for an activity and by specific product standards, set upper limits on the hazardous content. In other cases an original economic approach is replaced by a regulatory one. Regulation of cars is illustrative in this respect. Authorities started to phase out leaded petrol by introducing a differentiated petrol tax. Later they demanded catalytic converters on all new cars from a certain time. This ended the use of leaded petrol, since converters did not function with lead in the petrol. Another example is provided by agriculture. Here the use of fertilizer and pesticides were regulated via a quota-system and by quality requirements or outright ban on certain products.

Still, regulatory policy instruments are not sufficient. There is a limit to in how much detail you can regulate an activity. The resources needed for detailed control would be impossible.

This is especially true for diffuse sources and/or diffuse and long-term effects. Further, the direct regulation approach does not promote changes and innovation very well. It holds no or limited incentives. In these cases economic instruments are more efficient.

16.4 Setting the Right Price for External Effects

The damaging effects of emissions exemplified above, remain external to the cost-calculations in companies and hence are not included in the prices of the products. This is where the economic instruments may play an important role. Such instruments can "internalize" the costs of this type of environmental impact by assigning a tax to each unit of exhaust, to each kg of fertilizer and to each ton of CO_2. Such taxes will make the prices go up. Thereby they will create a dynamic (or continuous) incentive to innovate, to substitute or – at least – to try to reduce the use of the environmentally damaging products or methods to avoid paying or reduce the amount of the tax to be paid.

There are, in other words, some "social costs" of human activities, which are not automatically brought "into the equation".

The economic instruments, i.e. taxation, provide a way to internalize these costs into the private calculations. In this way private and social costs are added together to make up the full costs for the environment of human activity and thereby make the prices "tell the truth" [Weizäcker, 1997] about the environmental costs of a given commodity or service.

For micro-economic theory the internalization of social costs represents a problem of principle. It has correct (fair and firm) marginal pricing as a precondition for efficiency in cost distribution and resource re-allocation via the market. But the estimation and quantification of the social costs of different kinds of environmental damage are very difficult to establish, and any calculation will be full of uncertainties and reservations. Fixing the tax-level will therefore not come up to these micro-economic requirements, which are, by the way, also hampered by many other uncertainties and reservations in their practical application. Rather, deciding the level of the taxation will be much more of a "trial and error" exercise, depending on political support and drawing on experiences from other areas and from other countries and then correcting the tax-level as experiences are gained.

16.5 The Polluter Pays Principle

Quite a few environmental policy principles have been developed over the recent 30 years and most notably since 1987, when the Brundtland Commission Report Our common Future was published. For the economic instruments, *the polluter pays principle* is the oldest, the most widely recognized, taken up in legislation across the globe. It was adopted in the 1st EU Environmental Action Programme back in 1973 and included in the EU Treaty of 1992/93, Art. 174/EC. It was also included in the UNCED-Rio-Declaration from 1992. The key issue is, what should be included to fulfil this principle, i.e. when can the polluter be said to have paid (all the costs of his activity)?

Like most other areas we have here witnessed a historical development, changing the notion and the understanding of the polluter pays principle as to what should be included for full cost coverage. The main distinction goes between environmental fees/charges and environmental taxes. Suggestions for moving into taxation were heard all the way from Pigou in the 1920's till Baumol and Oates in the late 1970's into the 1980's. It was not until the latter half of the 1980's that the first environmental taxes were actually introduced.

16.6 Charges or User Fees

Charges are defined as the payment which should cover the proven expenses for handling waste or providing a resource such as water. The charges include costs for collecting sewage and treatment of wastewater in treatment plants collecting and incineration of solid waste collecting and depositing solid waste on landfill collecting and managing hazardous waste, either by incineration, or storage cleaning or depositing polluted soil from so-called brown fields

The companies responsible for these services are in many EU-countries run by, or owned by, the municipality or by the regional government, but private companies are also involved, especially in the solid waste-handling sector.

As the handling cost for the clean-up operations are not taking into account the wider implications and wider social costs of the economic activity, they will never be able to achieve the full "internalization" of these social costs. Still, within their scope, the charges will have some internalization effect as these costs will influence the behaviour of companies and consumers in the direction of avoiding or minimizing the amount to be paid. If charges were not required there would be a social redistribution via the state for the benefit of those, creating the pollution. The costs would then have to be paid by the ordinary taxpayer.

Data on charges are not available in Eurostat, (the EUs Statics Bureau), or EEA, the European Environmental Agency, on the charges collected in the EU-countries on only the taxes. But they are available nationally. As an example the fees and charges paid by Danish users in 1998 and 2004 are shown in Table 10.1 together with the environmental taxes paid these same years. It is clear from the table, that the relative increase in the charges is higher than the relative increase in the taxes. The main increase comes from charges for solid waste handling, which has actually doubled within these 6 years with the biggest "jump" from 1998-2000. The reasons seems to be cost increase at the handling utilities, including expansion of the handling capacity, a rise in the amount received and a slight increase in the proportion of private companies, active in the solid waste sector.

Setting a Price for Water Services For the publicly owned utilities the charges may cover the actual costs of running the operations, but may not exceed that level. Then they would turn into profit making, i.e. act as a hidden and non-decided taxation. The charges must, put differently, not move beyond making the services "expense-neutral".

The responsibility for defining the charges is normally that of the municipality or region. The city council or regional council in these cases appoints and constitutes the board of such companies, which decides the charges.

The charges may be fairly easy to calculate from the cost of operations. But it is less clear how to divide charges between a basic and a volume-dependent part of the charge. The cost for wastewater treatment is by far dominated by the basic cost for running the treatment plant, which is volume independent. Still, if the charge is volume-dependent, that is, dominated by costs per cubic meter, it will work as an incentive to decrease water use. This was dramatically illustrated when charges for water were introduced in Central and Eastern Europe. Water use decreased from more than 400 l/capita and day to less than 100 l/capita and day in a few years. A further complication is that normally the costs for water and wastewater management are combined into a single charge. The user pays for the volume of water used, regardless of how it is used and polluted. In addition many water companies do more than simply take care of water. They e.g. ferment their sludge to produce biogas, which is sold, and they may use residual heat in wastewater e.g. by a heat pump to feed into the district heating. It is not clear in which way the costs and gains from these activities enter into the definition of the charges.

In general only small industries use municipal water and municipal treatment plants. The larger industries most often have their own water supply and thus are independent of the municipal policy for setting charges. The cost for their water use is instead decided by the costs connected with fulfilling the conditions for water withdrawal and concentrations of pollutant in the effluents as decided in their licences. But in case the country or the region has put a tax on water use, this tax will have to be paid also by companies with their own water supply, as the objective of the tax is reduced use of the water resource as such. This is yet another demonstration of the difference between the fee and the tax.

16.7 Environmental Taxes

Introducing Environmental Taxes have become increasingly popular with most governments in recent years. It all started in the late 1980's with an OECD declaration by the member countries'

Environmental Ministers in June 1985. This was a pledge for the use of the polluter pays principle and initiated an extensive survey of the use of economic instruments among the member states. The study [Opschoor & Vos, 1989] found a number of charges but in reality no environmental taxes. The Japanese SO2 tax was the only exception. In addition taxes on petrol in the Netherlands and Scandinavia were identified.

In Denmark, the petrol tax was introduced as far back as in 1927, but at a low level. Petrol taxes were, however, subsequently raised considerably. In conjunction with the first and the second "oil crises" in 1974 and 1979 respectively an increase of petrol tax was introduced to halt a rise in, or to reduce, the petrol consumption. At the same time a shift from oil-based to coal-based power generation was initiated. Both measures were made to reduce the Danish dependency on oil and the damaging influence on the balance of payment. These taxes were, therefore, not originally founded on environmental concerns, but were increasingly seen that way, as the concern for the environment came firmly on the agenda with the 1987 Brundtland Report and the Rio summit in 1992.

OECD has compiled information on the level and importance of the "environmentally related taxes" for its 30 member states. Table 10.2 A-C provides an overview of the taxes for selected countries, related to GDP, to total tax revenue and per capita.

16.8 Charging resources – the case of water

Normally local authorities have the responsibility to provide the citizens with access to clean water, and water and wastewater systems are public utilities. Problems in management and financing of public water supply and sanitation systems, however, have led to different partnerships with the private sector, and throughout the world, there is a strong growing trend towards the participation of the private sector in the management and operation of water and wastewater enterprises, and increasing reliance on private finance for sector investments. In the United States, some 40% of the water and wastewater sector is in private hands. In France, local governments own the infrastructure, but a growing number of governments – now accounting for about 75% of all urban water connections in the country (though less for sewerage) - have opted to delegate the operation to private firms under management contracts, leases or concessions. Similar arrangements are spreading in Spain and Italy and are also being adopted in cities in Latin America, East Asia and Africa. Private sector participation has also taken hold in the transforming economies of Central and Eastern Europe.

For water supply and sanitation systems to be sustainable, all their costs should be covered. In all countries, cost containment should be an important objective of public utilities. It is of crucial importance in developing countries, where too many people still do not have access to services. Implementation of any sustainable policy should be affordable. The fastest urbanisation rates are in areas where there are very limited possibilities to design systems with a longer time perspective. Possibilities to implement different water and sanitary systems depend on willingness to pay, the gross domestic product per capita and costs involved in the different systems. Another important factor is time.

The major features of water infrastructure in the industrialised world are summarised as high coverage of water supply, a sewerage system securing public health and control of water borne diseases, and functioning wastewater treatment plants.

The western-world type of solutions characterized above, with centralised water and wastewater handling systems including water and sewer nets, costs a minimum of about $US 150 to 300 in capital costs per person. Large investments in this sector have been made in Central and Easter Europe as well as in the western world since the systems change in 1989-91. In Southeast Asia, the per capita cost of sewer connections in urban areas in 1985 varied from $US 45 to

$US 400 with a median cost of approximately $US 80. To this must be added an annual water charge in the region of $US 5 per person served. Low-cost on-site alternatives cost $US 13-30 per person in urban areas, and $US 5-20 per person in rural areas.

Public investments in water infrastructure were typically around 0.4% of the GDP. For people on a low-income level, for instance below $US 500 per year, this would mean a yearly investment in water infrastructure of $US 20.

For a variety of reasons, water supply projects commonly fail to reach their anticipated goals. Little attention has been paid to consumer demand for water supply and sanitation. It is typical to assume either that everyone will want to connect to the system, at whatever price that is charged, or that public health benefits are so important to the community and the services will be so heavily subsidised that no one will have reason not to connect. Normally it is assumed that as long as financial requirements for new water-supply systems do not exceed 5% of income, it is "affordable" and the household will make a connection to the system and be able to pay the subsequent recurrent charges. In sanitation planning, the general rule-of-thumb is that if the monthly charges are less than 3% of household income, it is assumed that the household has the ability and willingness to pay for the improved service.

Probably the most reliable source of information concerning willingness to pay is to be derived from pursuing surveys of organised and informal water-vending activities in both cities and rural areas (Rogerson, 1996). Because of the difficulties associated with cost recovery for piped supplies with public outlets and despite the fact that they are often illegal, water-vending systems have been formalized as a means of supplementing or replacing piped distribution systems. This is suitable to communities where a socially beneficial vending system already exists and can be improved, and where other options are technically, economically or otherwise unsuitable.

Water vendors who take water from an available source and subsequently deliver it in containers to households or fill household containers from their vehicle tanks serve millions of people in villages and cities throughout the developing world. In Jakarta roughly 32% of the city's 8 million inhabitants purchase drinking water from street vendors. The distribution of water by vendors is expensive, regardless of whether vehicles are powered by people, animals or engines. It is generally the case that households served by vendors pay higher unit charges for water than those directly connected to a piped system. Beyond cost considerations, vending is sometimes also linked to health problems, as hawkers may sell from polluted sources or from fouled containers. People may obtain water by

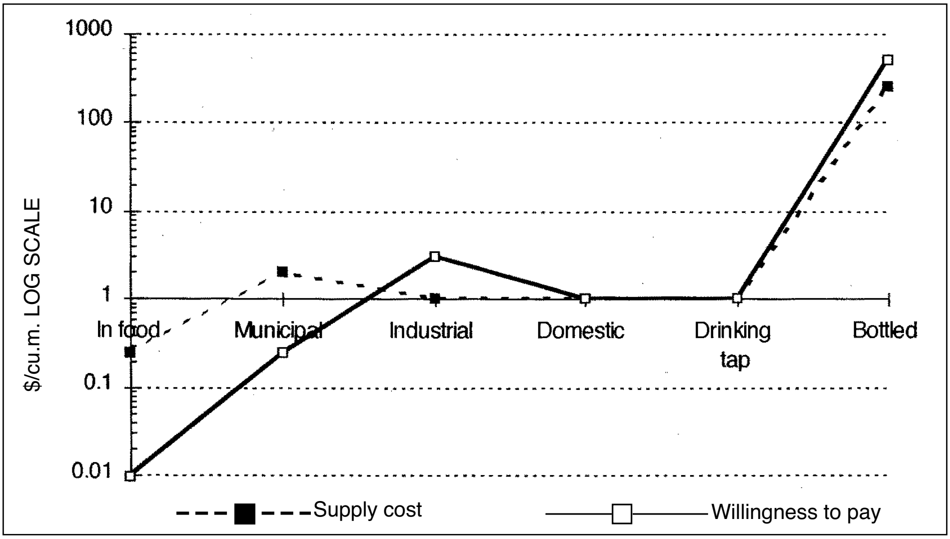

Figure 16.1 Supply costs of water (indicative) and levels of willingness to pay (indicative) in arid environments, (Allan, 1995a).

purchasing it from vendors who are licensed operators (kiosks) directly or from distributing vendors who buy water from the kiosks.

Studies on water vending have shown that households sometimes pay a higher fraction of their income for water compared with the common role-of-thumb analysis that households in the developing world can afford only 3 to 5% of their income for improved water supplies. The willingness to pay for water is closely related to water use. In arid environments the willingness to pay for industrial and domestic use (including drinking water) may be 1-2 \$US/m^3 and as high as 500 \$US/m^3 for bottled water (see Figure 16.1).

The willingness to pay for irrigation water for agriculture is much lower (about 1 US cent/m^3) and irrigation water is often heavily subsidised from the state. The supply costs of the water are in the same range as the willingness to pay, except for irrigation and municipal water.

Chapter 16 sources:

Lars Rydén. The Baltic University Programme on-line sustainable development course http://www.balticuniv.uu.se/index.php/5c-waste--sustainable-end-of-life-of-products

Box 15.1 Industrial symbiosis from Chapter 11. Green Engineering by Lennart Nilsson in Cleaner Production – Technologies and Tools for Resource Efficient Production in Environmental Management, Book 2 Baltic University Press. http://www.balticuniv.uu.se/index.php/boll-online-library/827-em-2-cleaner-production-technologies-and-tools-for-resource-efficient-production

The Baltic University Programme book series A Sustainable Baltic Region

http://www.balticuniv.uu.se/index.php/boll-online-library/819-a-sustainable-baltic-region
Book 3 Sten Karlsson Chapter 7 The valuable metals
Man and materials flows – Towards sustainable materials management
Accenture. Adopting circular economy business models is essential to building sustainable organizations.
http://www.accenture.com/us-en/Pages/service-circular-economy-innovation-video.aspx

UZWATER

This compendium is produced for the master level course in the UZWATER project. It consists of some newly written material as well as previously published texts extracted from freely available books, reports and textbooks on the Internet, dominated by publications from the Baltic University Programme. The sources used for each chapter is listed at the end of each chapter. The compendiums of the Uzwater project is produced exclusively for Master students free of charge at the participating Universities and is not to be sold or be freely available on the internet.

The UZWATER project is an EU TEMPUS project. It includes 8 universities in Uzbekistan and deals with university education for sustainable water managment in Uzbekistan. Uppsala University and BUP is one of the EU partners in the project. Lead partner is Kaunas University of Technology.

The main objective of the project is to introduce a Master level study program in environmental science and sustainable development with focus on water management in eight Uzbekistan universities. The curriculum of Master Programme includes Environmental Science, Sustainable Development and Water Management.

The Sustainable Development unit will include the basic methods used in Sustainability Science, in particular introduce systems thinking and systems analysis, resource flows and resource management and a series of practical tools for good resource management, such as recycling, energy efficiency, etc.

The specific objectives of the project are:

- to establish study centers at the partner universities in Uzbekistan
- to improve the capacity to train master students with expertise to address the severe environmental and water management problems of the country;
- to support the introduction and use in Uzbekistan of modern education methods, study materials, and e-learning tools;
- to encourage international cooperation at the partner universities;
- to strengthen capacities to provide guidance to authorities and the Uzbekistan society at large;
- to ensure the visibility and promotion of the Master Programme through web pages, printed material and cooperation with society;
- to ensure continuity of the Master Programme and long-term support of the project outcomes at partner universities beyond Tempus funding.

http://uzwater.ktu.lt