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Chapter 1

Introduction – setting the scene

During the last decades there has been an unprecedented progress in living conditions, public health, sanitation, child mortality, communication, and the global economy. But there is no such thing as a free lunch and progress comes at a cost. Still, our behaviour does not reflect such an understanding. We have treated the capital of the Earth as if it were free: coal, oil, gas, uranium, and minerals are extracted, and water is used wastefully, without concern that we are draining the capital. Agricultural land has been mishandled, and air, rivers, lakes, and oceans have too long been considered freely available and have served as bottomless waste bins.

1.1 WHERE WE ARE TODAY

A few numbers may illustrate how the conditions for the global population have developed during the last few decades. There has been impressive progress:

- Three quarters of the global population now have access to sanitation and to clean drinking water at home.
- World life expectancy has increased from 45 years in 1950 to almost 73 years in 2021.
- Around 80% of all children aged one year have been vaccinated for at least one disease.
- World literacy rate has increased from 67% in 1976 and to almost 87% today.
- The urban population has increased 4.3 times since 1960, much faster than the global population increase of 1.6 times. The urban population grew from 34% to 56% in the last 60 years.
- The number of deaths caused by natural disasters has *decreased* during the last century, not because of fewer extreme events, but due to better warning systems and better protection in many places.
- Four out of five people in the world have access to some electricity.

But still:

- More than 2 billion people have no access to clean water at home and more than 2 billion people lack access to basic sanitation, like toilets and latrines.
- More than 800 children younger than 5 years die every day from diarrhoea due to lack of clean water.
- More than 800 million people face chronic food deprivation.
- More than one billion people lack electrical power.
- Economic inequality is bizarre: in 2021 the world's richest 1% have more than double the wealth compared to 6.9 billion people or 88% of the global population.

1.2 HOW WE GOT HERE

Several developments have occurred, isolated or interconnected, over recent decades. Each one of them can give a picture of how we got here today[49]. Development and growth have come also with an environmental cost:

- Total CO_2 emissions increased from around 9.5 Gt/year in 1960 to almost 40 Gt/year according to the IPCC Sixth Assessment Report 2021[50].
- Electricity generation using fossil fuels has increased from less than 6000 TWh in 1960 to around 16 000 TWh in 2020.
- Carbon emissions are set to hit an all-time high by 2023. Just 2% of pandemic recovery finance was being spent on clean energy[51].
- Biodiversity loss is apparent today and is a clear and distinct way to measure the health of our planet. Wildlife is the canary not only of coal mines, but of the entire planet.
- Deforestation contributes to the increasing greenhouse gas concentration in the atmosphere.
- Land area for agriculture is around 38% of the global land surface. Global cropland area per capita was around 0.45 hectare in 1961 and has decreased continuously since then to 0.21 hectare in 2016[52]. There is a great risk that projected cropland expansion and intensification will take place in regions that are valuable for biodiversity conservation, such as tropical areas of Latin America, Central Africa, and South-East Asia.
- An average of 14 million people every year were reported displaced by extreme weather disasters in the period 2008–2014[53]. In 2021 increasing intensity and frequency of extreme weather events are already causing more than 20 million people to leave their homes[54].

Efficiency and productivity have been guiding stars of our industrial societies. We have looked at environment as something 'over there' and have not understood that we are part of it. Chief Oren Lyons expresses our relation to Earth like this: '*What you people call your natural resources our people call our relatives*'. We need to recognize that all things are connected. If Earth suffers then we will suffer. Therefore, it is imperative to comprehend the water–climate–energy–food–economy–lifestyle nexus. Let us look at some of the developments:

- *Coal* was the remarkable resource that made the industrial revolution possible. Then we detected the cost for coal mining: mine accidents, water pollution, mine explosions and fires. We suffered from air pollution caused by coal burning and became aware of its climate impact. We paid for the coal but did not pay for the damage that it caused.
- *Oil* was the 'clean' replacement for dirty coal and so much easier to handle. It was the basis for the internal combustion engine and made our mobility possible. However, it also caused accidents during exploration, leakages during transportation, water pollution, destroyed wetlands and marine life, threatened the subsistence of farmers and fishermen, and led to geopolitical conflicts and wars. Again, the price of oil does not take the costs for accidents and environmental damage into consideration.
- *Natural gas* became the cleaner alternative to coal. So convenient to transport in pipelines. However, we had to recognize that natural gas flaring and methane leaking from pipelines and oil wells have a huge impact on our climate.
- *Nuclear power* promised to satisfy our electrical energy thirst for many generations. Then Three Mile Island, Chornobyl, and Fukushima reminded us about its vulnerability. Moreover, we did not find a dead certain solution to the final disposal of uranium.
- *Food production* was made more efficient by using irrigation, fertilizers, and machinery at large scale, but it led to water scarcity. Monocultures and too much irrigation impoverished the soil. As hand pumps were replaced by electric pumps for irrigation, groundwater levels shrank to alarming levels.
- *Food habits* in the rich part of the world have changed rapidly. Meat production has increased four-fold since the 1960s. This is problematic since meat is an 'inefficient' food source. Food waste, both in the low-income and in the high-income world, but for different reasons, is unacceptable. The food on our breakfast or dinner table has often travelled long distances from other parts of the world.
- *Industrial production* has been the sign of increasing welfare. However, waste products and harmful components leaked into the environment, polluted the air, caused damaged water sources, and poisoned fish, which in turn led to unsafe food and human suffering.
- *Mobility* is greater than ever. We gained freedom never seen before using our cars and aircraft. Now the price has become apparent in terms of air pollution, greenhouse gas emissions, and lack of resources.
- *Economic inequality* is greater than ever, both within nations and between countries. The idea that we can grow indefinitely in a finite world is absurd. Only a minority of the global population can enjoy all the benefits of our progress. We designed economic systems that favoured rich people and affluent nations.

- *Impatience* – in the high-income world we expect instant reward:
  - *Electrical energy*: even on the coldest winter day or the hottest summer day we take it for granted in wealthy countries to have access to all the electric power needed for machinery, heating, and cooling. This requires high power capacity, designed for the peak demand. The huge development in power electronics for electric drives has made pumps and compressors so much more efficient.
  - *Food*: we have got used to fresh fruit and vegetables being available all around the year. In my country Sweden we could buy apples from our antipode New Zealand at a lower price than local apples during our own harvest season. Cheap energy and transportation made it possible.
  - *Mobility*: in a country with four distinct seasons, we can afford to escape to warm destinations during unpleasant winter weeks. If the summer weather is not sufficiently pleasant, we may rush to get a more enjoyable summer elsewhere.

For too long we have perceived nature as something that needs to be conquered and be used to satisfy the needs of humans. We have come to a point in global development, where we are forced to recognize that everything is connected and that we are part of nature. If we are ever going to solve critical issues, we must appreciate the interconnections between our actions, consumption, economy, and nature. Systems thinking is one way to grasp all these connections.

1.3 GOING FROM HERE

To manage the complexity of the global resources we need to systematically analyse how they are coupled. In the rest of the book, we will try to describe where we are and why a systemic approach may help us. However, solutions depend not only on science and technology. We need to achieve a better understanding how we as humans set our priorities and what kind of moral compass that we have.

The goals or performance criteria of wicked problems like global resources, cannot be defined objectively. Instead, they are the result of difficult negotiations and compromises between different interests. However, as a control engineer, I look for some performance, so that I can compare achievements ('measurements') with the goal and find ways to reach corrective actions. Pledges being made at conferences and international meetings are nothing else than 'reference values' or 'desired values'. If they are not connected via 'measurements' to some action, they are meaningless and empty wishes.

1.4 SOME SCENARIOS

To describe the complex interactions between water, energy, food, economy, and climate we will try to follow some elements from cradle to grave, from source to final use and disposal. This will hopefully form a basis for a more systematic description of the couplings in the following chapters.

1.4.1 Fossil fuels

Every *minute*, around the clock, the world consumes:

- More than 10 000 m^3 of oil
- Around 14 000 tons of coal, corresponding to 12 700–20 000 m^3
- More than 7 million m^3 of natural gas, corresponding to 5000–6300 tons (at 0°C and 1 atm or 100 kPa).

The volume of an Olympic swimming pool is 50 m × 25 m × 2 m = 2500 m^3. Hence, if we filled the swimming pool with oil and supplied the world, it would be emptied in 14 seconds. Likewise, another pool filled with coal is emptied in 8–12 seconds. The famous Trafalgar Square in London has an area of 12 000 m^2. Natural gas produced (at normal pressure) will fill a volume to cover the whole square and rise to a height of 52 metres, to the top of the Admiral Nelson statue, in 5 seconds. Around the clock.

This is the culprit of global warming. Figure 1.1 is a schematic of the life cycle of oil, from extraction to final use.

Oil is extracted as 'conventional' oil (crude oil) or as 'unconventional' oil, usually extracted by hydraulic fracking (fracturing) or from tar sand. For the oil extraction, water is used, sometimes as steam to facilitate pumping, sometimes as heated water to get rid of bitumen in the tar oil. In hydraulic fracturing, water is pumped deep into the sediments at extremely high pressure to fracture the sediment where oil and gas are trapped. Several chemical components are added to the water, many of them toxic. Water is polluted (called 'used water' by the operators) and has an impact on the environment. Extraction produces CO_2 emissions from the energy-requiring operations as well as methane emissions caused by leaking natural gas. Flaring of natural gas contributes to both greenhouse gas emission and air pollution. There are apparent risks for large volumes of oil leaking out into the environment, on land or in water, due to accidents or to human errors.

The refining and processing of oil products will further require both water resources and energy. Transportation of oil, in pipelines or in ships, is not without risks. Pipelines may leak, and oil tanker accidents have taken place. Transportation requires energy, thus producing more emissions.

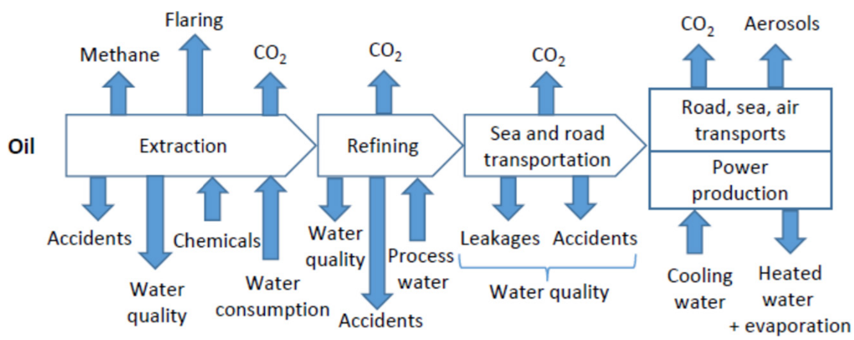

Figure 1.1 The life cycle of oil.

The final user of the oil product, burning the oil, be it for electric power production or for transportation, will cause further emissions of greenhouse gases as well as air pollution from particle emission. Cooling thermal power systems requires water that is primarily heated but also consumed due to evaporation.

Coal has a similar life cycle to oil. For centuries coal mining has been recognized as a dangerous operation, for workers and for the environment. Land is destroyed and water is contaminated. Coal is both the largest source of electricity generation and the largest single source of CO_2 emissions.

Natural gas has a large carbon footprint, since the main component is methane. Hydraulic fracturing is a vast source of natural gas production. Leakage of gas is a significant source of global warming risks. This happens both around gas extraction and in pipeline transportations. Natural gas is increasingly replacing coal as an energy source for power system operations.

1.4.2 Food

Every hour, around the clock, the world eats 40 000 tons of meat. For this consumption, more than 8 million animals are slaughtered. Some 95% of them are chickens, and then it includes 170 000 pigs and 35 000 cattle. Every hour.

Ruminant animals – cattle, sheep and goats – can eat grass, but are increasingly fed with cereals and soya to enhance the production rate. Figure 1.2 is a rough illustration of the life cycle of the meat that we eat.

Water is essential for the growth. A significant part of farmland is irrigated, and this is a huge threat to water resources in many places. Chemical fertilizers and pesticides are added, influencing both soil and water quality. Farming machinery contributes to the carbon footprint. Land use for the cattle raising is a significant cause of deforestation around the world. Cattle contribute to both water pollution and to methane emissions. Industrialized food processing has a significant footprint of both water and energy. Transportation and distribution look quite different in wealthy and in low-income countries. Significant amounts of food are transported long distances between continents and will, of course, contribute to food's large carbon footprint. In low-income countries, less availability of efficient transportation and safe storage will cause food waste. In wealthy countries, most of the food waste takes place close to the consumer.

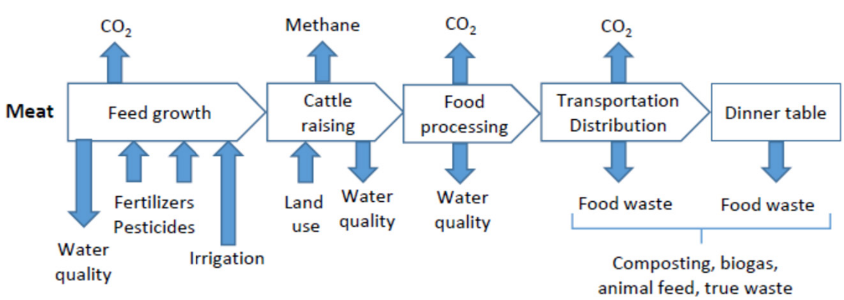

Figure 1.2 The life cycle of meat.

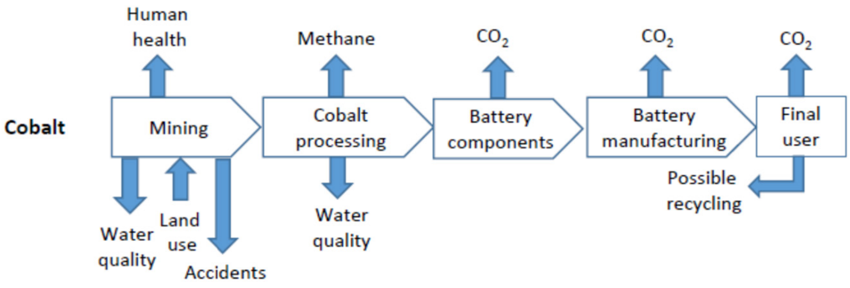

Figure 1.3 The processes from cobalt mine to car battery.

1.4.3 Renewable energy – critical minerals

Renewable energy comes with a lot of promises to replace fossil fuels. Being a variable source of energy, there will be an increasing requirement of storage capacity. Electric cars need efficient batteries. The need for critical minerals and metals like cobalt and lithium is apparent. Figure 1.3 indicates some of the interactions in the chain of processes from mining to battery manufacturing for cobalt.

Mining operations have a huge impact on water resources and water quality as well as on human health. The cobalt is processed in various steps and most of the cobalt mined today is transported from DR Congo to East Asia. Battery component and battery manufacturing have probably a large environmental impact, but much of this information is not openly available. Transportation causes a carbon footprint. The final user, the electric car owner, needs to charge the battery. If the electric power is coming from fossil fuels, then the electric car will cause CO_2 emissions.

1.4.4 Economics

Economic systems favouring unlimited growth in a limited world have been driving global warming. There have been serious warnings for at least three decades, but the influence on the economic system has been insignificant.

Economic inequalities in the world, between nations and between individuals, have created two groups. The wealthy part is responsible for the major contribution to global warming, while the less fortunate part has been subject to the most serious consequences. Economics and lifestyle are closely coupled to water use, energy use, food habits, and global warming.

1.5 OVERVIEW OF THE BOOK

To understand the impact of the global development it is necessary to consider not only each of them separately but to see how they are connected in a network, illustrated in the highly simplified diagram in Figure 1.4. Water scarcity problems cannot be solved in isolation but must be understood in relation to climate, energy, food, and lifestyle. Similarly, energy challenges must be solved taking the other 'components' into consideration.

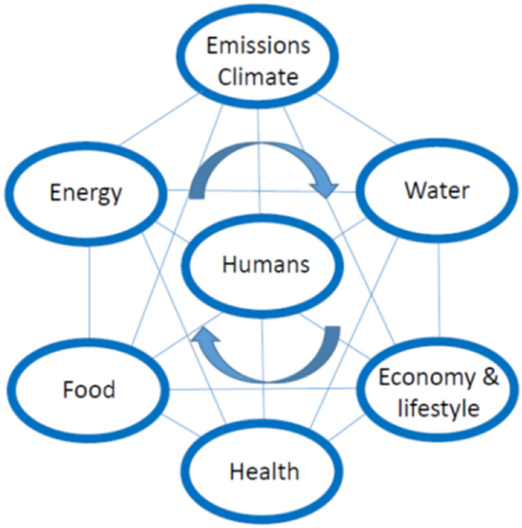

Figure 1.4 The complex problems that we face today cannot be solved in isolation. They are interconnected and influence each other bi-directionally.

	Climate	Water	Energy	Food	Health	Economics &Lifestyle
Climate	**Ch. 3–4**	4.3, 4.4, 4.6, 4.8, 5.1, 5.2	6.1, 6.3, 6.6, 6.10, 6.11	5.6, 7.1, 7.2	4.7, 4.12	7.3, 8.1, 8.2, 8.3, 9.2
Water	----	**Ch. 5**	5.2, 5.3, 5.4, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 6.12, 6.13	5.6, 6.6, 7.3, 7.4	5.1, 5.7, 6.8	5.5, 5.7, 8.1, 9.4
Energy	----	----	**Ch. 6**	6.6, 7.3, 7.5	6.13, 6.14	8.1, 8.4, 9.4
Food	----	----	----	**Ch. 7**	7.6, 7.7	7.6, 8.1, 9.4
Health	----	----	----	----	3.7, 4.7, 4.12	8.3
					5.5, 6.5, 6.8, 6.13, 6.14, 7.7	9.4
Economics & Lifestyle	----	----	----	----	----	**Ch. 8–9**

Figure 1.5 Graphical table of content of interactions. The matrix is symmetric, indicating that each interaction has a clear cause–effect direction. Here we have chosen to show them as bidirectional. For example, water has an impact on energy operations, and energy production has a consequence for water resources or water quality.

In the endeavour to present this complexity in some systematic manner each one of the couplings should be described while still not being able to demonstrate the complete picture. The reader will find out if this is accomplished in the book. Figure 1.5 is a graphical table of content, illustrating where the various interactions are investigated. For example, to find how water and energy are related we look at the connections both from a water and an energy perspective, and the interactions are analysed in sections 5.2, 5.3, 5.4, 6.4, etc. Similarly, the interactions between other components are indicated in the figure. Some sections, for example in Chapter 6 on energy or Chapter 8 on economics are descriptions that are specific for that topic, without apparent descriptions of interactions.