Global Challenges for a Sustainable Society

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Summary

This is a summary of the Massive Open Online Course (MOOC) KULeuvenX: Global Challenges for a Sustainable Society, based on the provided study guides part of the Engineering and Sustainability: Philosophy and Global Challenges course of the Bachelor of Engineering Technology at KU Leuven.

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Disclaimer

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1.2.1 Climate change over geological cycles

We know climate change is partly a natural phenomenon because of the research done with Antarctic ice. Figure 1 clearly shows a natural cycle in temperatures over the last 800,000 years. Other evidence pointing to this conclusion can be found in landscapes which have been altered by moving glacial ice.

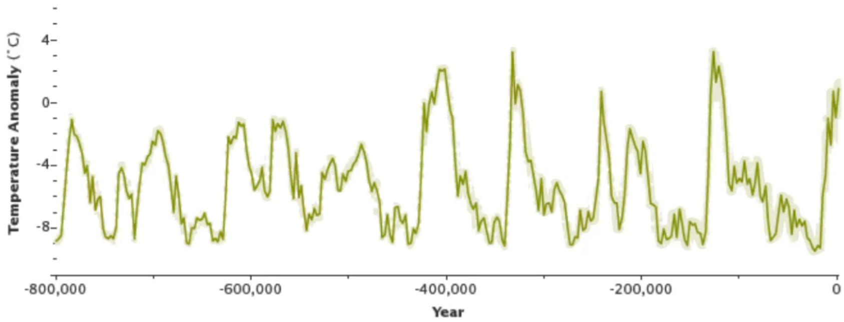


Figure 1: Antarctic ice records

1.2.2 Causes of climate change

There are a few factors which cause the change in climate on earth:

- Variations in the earth's orbit around the sun (eccentricity)
- The axis of the Earth from pole to pole is tilted compared to this plane of movements, this is time dependent (obliquity)
- Precession of the Earth.

Of these especially obliquity is important. It can lead to very hot summers and very cold winters without a lot of snowfall. This leads to a shrinkage in the ice coverage of the Earth which leads to ever warmer temperatures. This feedback loop amplifies itself (albedo feedback). Another factor is the physical place of land mass. If it is close to the poles, ice can easily form and reflect heat back into space. Volcanic explosions are known to have an influence as well due to their tendency to throw light blocking particles in the atmosphere. Lastly the activity of the sun itself plays a role in the climate of the earth.

Us humans have had an impact since the industrial revolution by throwing tiny particles in the air due to burning fossil fuels, cooling the earth. This effect is overshadowed by the fact that we emit a lot of greenhouse gasses whilst we burn the same fossil fuels. An illustration of our impact on CO_2 levels can be seen in figure 2.

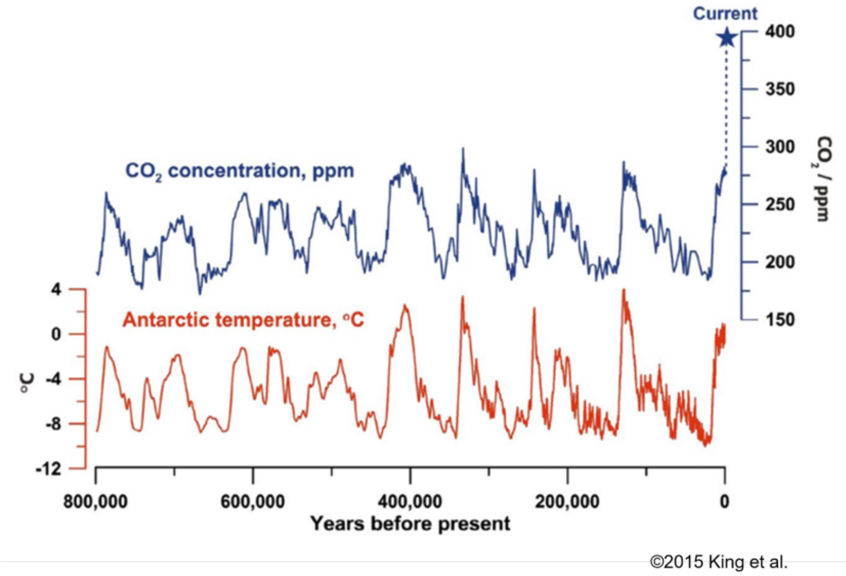


Figure 2: Historic CO_2 records

1.2.3 Human cause

Global temperatures have increased by 1.1 degrees Celsius since industrialization. There are five lines of evidence that our greenhouse gas emission is responsible for this:

1. We see that our activities with fossil fuel and cement produces about 9Gt of carbon per year, whilst the natural rate is only 0.9Gt per year. Luckily for us, the earth absorbs about 5.5Gt per year back into itself, otherwise CO_2 levels would be double of what they are right now.
2. We also look at the isotopic ratio between C13 and C12 carbon. The gradual lowering of this ratio suggests a lot of plant derived carbon sources (fossil fuels) have been dumped in the atmosphere.
3. The physical mechanism by which greenhouse gasses prevent infra-red radiation from escaping our atmosphere has been proved already in 1850.
4. Climate models where factors can be individually adjusted also show a large effect of our activity.
5. Radiative forcing is what happens when the amount of energy that enters the Earth's atmosphere is different from what leaves it. This, again, is influenced by greenhouse gasses.

1.2.4 Radiative forcing

As discussed in the previous section, radiative forcing has an impact on our climate, but how does it work? The only way in which the earth can exchange energy is through radiation interactions with space. This is depicted in figure 3. In the end, about 31% of the solar radiation is reflected. This yields a net solar radiation of about 235 watts per square meter. In reality this net radiation is counteracted by the natural infra-red radiation of earth, balancing the entire system.

By emitting too many greenhouse gasses, we have brought this balance to an end, resulting in a net increase of energy. To investigate the forcing effect we have, we can look at a concept called radiative forcing. This is a very important concept in the whole climate research and also very important for policy implications because with this metric, we can estimate the effect of different forcing factors.

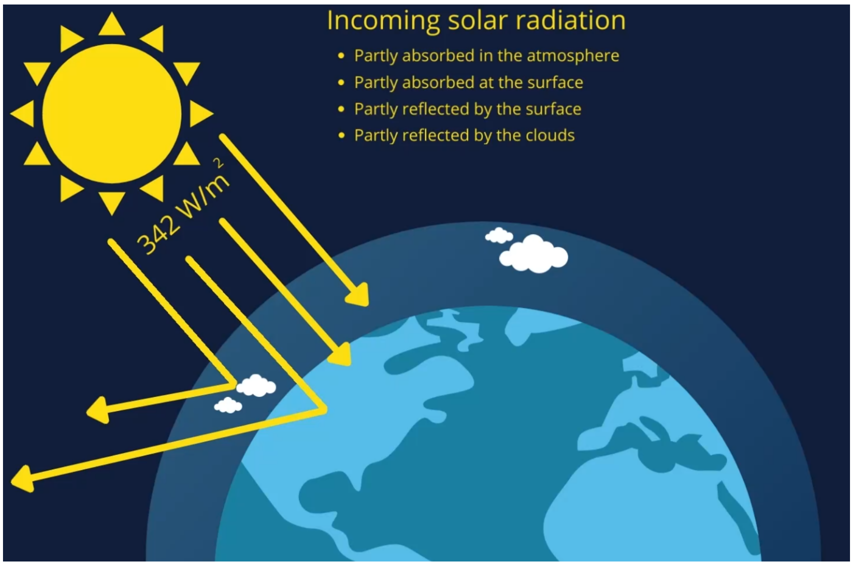


Figure 3: Earth's radiation exchange

So when we sum everything up over the time period 1750 till now, then we can also look at the average radiative forcing over that time period. The radiative forcing by carbon dioxide is the largest contributor - so that's why we talk about CO2 a lot when we are talking about climate change - namely 2.16 watts per square meter. Other well-mixed gasses also play an important role, so they also cause a positive radiative forcing. Ozone as well.

1.3 Climate targets and pathways

1.3.1 International agreements

A very important milestone in the climate negotiation is the Paris Agreement of 2015. The goal of this convention is to stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system by keeping the maximum warming under 2 –preferably 1.5– degrees Celsius. This target is based on scientific research by the entire climate community worldwide called the Intergovernmental Panel on Climate Change (IPCC).

The IPCC bases their recommendations on hundreds of papers and years of research of how the emission of greenhouse-gasses impacts the Earth. Since there are so many aspects to climate change, they have formed five subdivisions:

Geographic Preserving coral reefs, Arctic and indigenous people, mountain glaciers and biodiversity hotspots.

Weahter Extremes like heat waves, heavy rains, droughts, wildfires, coastal flooding.

People Concern for impacts that disproportionately affect particular groups.

Monetary damage Global scale degradation, loss of ecosystems and biodiversity on a global scale could lead to global damages and making the world more difficult to live in

Climate system Concern for the large, abrupt and sometimes irreversible changes in the system. These are called tipping points as well.

1.3.2 Carbon budget

To reach our goal of keeping climate change to a minimum, we need to gauge how much we need to achieve for that. For this reason, the carbon budged was introduced: it is a measure of how much CO_2 we can still emit without going over the limit. Part of this budged has already been spent because we calculate the budged from the start of our industrialization.

Calculating this figure is not easy, but we can take some short-cuts: temperature is linearly proportional to CO_2 emissions. This is clearly shown in figure 4. This of course isn't conclusive evidence about the relationship and thus the prediction of our carbon budged can be wrong. A probability of 66% (the very likely range) has been chosen, meaning that the carbon budget is defined in a way that we have a 66% chance to stay within the temperature targets that have been defined by the Paris Agreement.

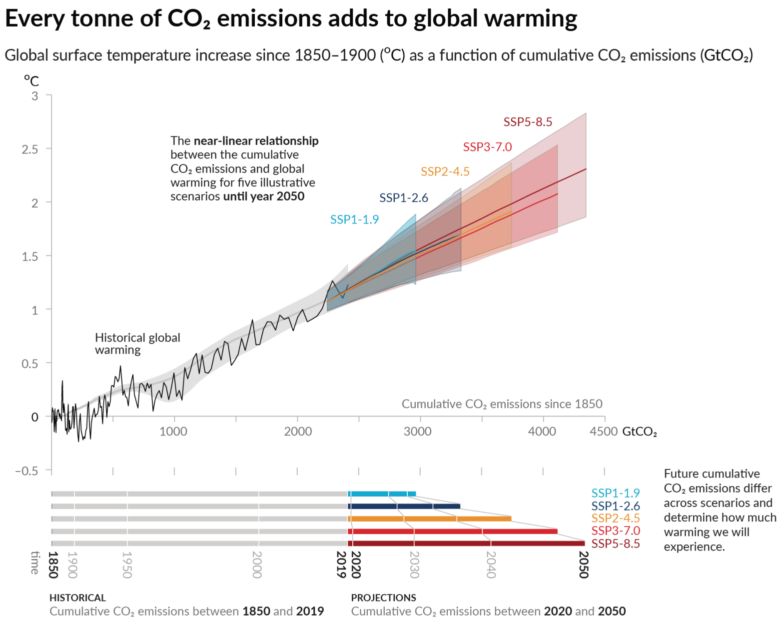


Figure 4: Relationship between CO_2 and temperature

1.3.3 Pathways

Because the exact time of emission is almost irrelevant, the IPCC has found four different pathways to reducing emissions. There are essentially 2 types: Strong reductions at the start with lower effort later down the line, and low effort now with (almost unrealistic) reductions later. They also rely very much on negative emissions, meaning that carbon is stored either in biosystems or in engineering systems

All pathways rely heavily on the reduction of fossil fuels. We also will have to do some land management: agriculture, forestry and other land use (AFOLU). Thirdly we can use bioenergy with carbon capture and storage (BECCS). The first two pathways mainly rely on the reduction of fossil fuels, the fourth pathway makes heavy use of BECCS and the third pathway combines both strategies.

If we look at our efforts to reduce our CO_2 use by looking at the Emission Gap report, we see that our policy has had an impact on our emissions. However, to conform with the Paris Agreement by 2023 we still have a gap of about 12Gt to fill.

1.4 Climate mitigation

1.4.1 What can I do?

An important resource of information is from the so-called drawdown project. Drawdown is the point in the future when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline. The drawdown project is the world's leading resource for climate solutions. Drawdown lists solutions based on effectiveness. So they estimate for a certain time horizon, in this case from 2020 to 2050, how much of the emission is either reduced or sequestered.

For example, by reducing food waste to an absolute minimum we can save about 90Gt of emissions which is equal to about 2 years of emissions. Switching to plant rich diets would also help enormously in reducing the impact of agriculture and food on the climate. Other important changes are along the lines of managing refrigerants better, increasing forest coverage, transitioning to clean energy... .

1.4.2 Individual action

There are four main ways to help fight climate change as an individual:

1. By using your democratic right, you can vote for political parties who take climate seriously. You can also participate in climate marches and activism to keep political pressure high.
2. Reducing your own carbon footprint: you can do this by changing habits such as diet, energy use, transportation choices... . The most effective starting point here is informing yourself.
3. Planet friendly investments by opting out of funds investing in fossil fuels. You can investigate in ethical banks and so on. Also inform yourself there
4. Support an up scaling of the transition. If you can spread these ways to fight climate change and motivate others to do the same, then together we can do it

1.5 What can we expect for the future

1.5.1 Climate scenarios

Running complete simulations of a possible future is expensive and difficult, that is why we introduced representative concentration pathways or RPCs. They are labelled according to their radiative forcing: RPC 8.5 is 8.5 watts per square meter, RPC 5 is 5 watts per square meter... .

Using RPCs we can make simpler models which reflect global warming. For example RPC 1.9 will get us to reaching our goals set on the Paris Agreement, while RPC 2.6 will probably lead to global warming by the end of this century. RPC 8.5 represents no change in climate policy and will have a large impact on our way of living.

Looking at the impact of this warming, we see that the poles of the earth will heat the most. There is also a disproportionate heating effect between land and water. This is because it takes a huge amount of energy to heat water compared to heating land. Wet regions will get even wetter and dry regions will get even dryer.

1.5.2 Highlight: sea level

1.5.2.1 Causes and predictions

As water heats up, it expands. This will – if climate change is not properly addressed – make sea levels rise significantly. Especially low-lying countries will be impacted by this change in a permanent and catastrophic way. Water which is stored on land in the form of glaciers for example is also a big factor driving rising sea levels.

Up until now, the oceans have absorbed about 90% of excess heat due to climate change. This is a good thing for us, as it protects us from a lot of the negative effects of climate change. It does however mean that most of the rise in sea levels is due to thermal expansion. Glaciers melting due to rising temperatures have also had quite the impact. Nearly every major glacier has significantly reduced in size over the last century.

The change in ice sheets at the poles can't be underestimated either. Every way in which we monitor these sheets has shown a large reduction in their size. All the resulting water of course ends up in the ocean, raising their level. If for example, the entirety of Antarctica would melt, we'd see a rise of 58(!) meters.

Current predictions estimate a rise of about 25 to 100 cm in the coming century.

1.5.2.2 Impacts and risks of sea level rise

As is shown in figure 5, the risks for coastal regions are very substantial when nothing is done about climate change. At current levels, a risk is already present for resource rich coastal cities. We can mitigate this partly by adapting to the changes, but not everything will be salvageable.

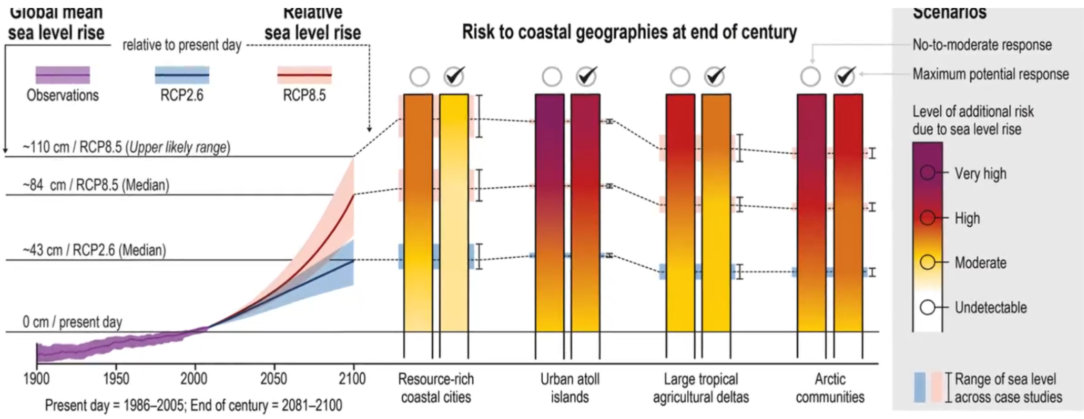


Figure 5: Burning ember diagram for sea level rise risks

The World Bank estimates that damages will cost associated with these risks will cost billions per year by the middle of this century. Especially since we have a tendency to build large cities near water. About 800 million people are at risk of facing the impact of rising sea levels and storm surges.

2 Biodiversity

2.1 Study guide

Module 2 (Biodiversity) sketches basic insights biodiversity, different types of diversity, in an historical perspective and with options for the future. Make sure to understand:

- The different types of diversity
- Historical evolution of biodiversity
- The importance of biodiversity
- How biodiversity can be measured and what the challenges in this are
- The important treats for biodiversity
- Different options to restore biodiversity
- Being able to interpret data with regard to biodiversity

Don't learn the specific examples by heart, do not learn specific vocabulary by heart (such as Cambrian or Cretaceous).

2.2 Types of diversity

git First, we need to define what **biodiversity** actually means. It is the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are parts. This includes the diversity within species, between species and of ecosystems

The first type of biodiversity is **genetic diversity** or diversity within species. It is the amount of naturally occurring genetic variation among individuals of the same species.

Another type of diversity is **species diversity**. This type is often defined as the number of species at a certain location. Figure 6 gives an indication of this diversity.

Thirdly, there also is **diversity in ecosystems**. There are a lot of different ecosystems around the globe: from the boreal forest at high latitudes to tropical forests around the equator, but also aquatic ecosystems like lake systems, coral reefs and mangroves count towards ecosystem diversity.

Figure 6: Diversity in species

2.3 Historical evolution of biodiversity

First, it is useful to mention that the plant Earth is about 4.5 billion years old and the first bacterial life emerged about 3.7 billion years ago. We can see the **increase** of both **terrestrial species** and **marine species** through time. The first vertebrates (notably fish) appeared 500 million years ago, the land plants 470 million years ago and the mammals 200 million years ago. Figure 7 shows this increase over time.

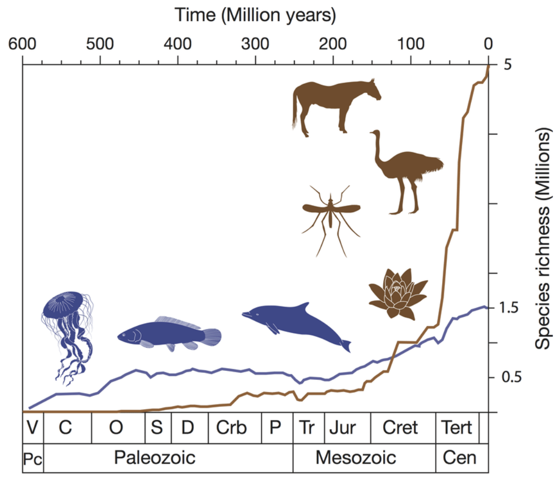


Figure 7: Increase of diversity and number of species over time

The process behind the increasing species richness through time is **speciation**. This is the evolutionary process by which different populations of the same species evolve to become distinct species. Today's species richness is only a fraction (between 2% and 5%) of the number of species ever present on Earth. Many species became extinct, either for no really identifiable reason (these are the so-called **background extinctions**) or as a result of a large-scale catastrophes (these are the **mass extinctions**).

Population declines of living species are hidden from global extinction numbers, but are shown in, for example, the **Living Planet Index**. This measure shows the evolution of the average population size of 21,000 animal populations across the globe. The living planet index shows a dramatic decline of 69% since the start in 1970. A problem with this index is that it gives no information about the fate of individual species, and that it is affected by a minority of populations with a strong negative trend.

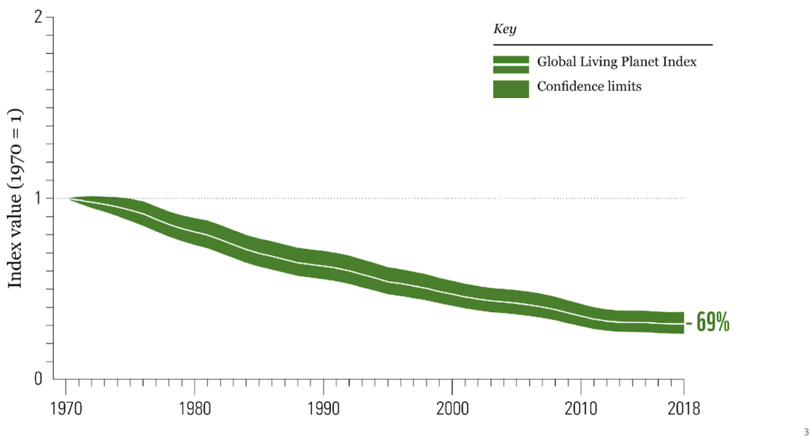


Figure 8: Living Planet Index

2.4 The importance of biodiversity

The human society depends on nature for its ecosystem services. **Ecosystem Services are the goods and services humans get from ecosystems**. This continuous and vital flow of ecosystem services from ecosystems to humans can be visualized by the ecosystem services cascade.

In the Ecosystem Services cascade of Figure 9, we see the integrated social-ecological system with to the left the ecosystem and to the right the human society. The ecosystem has its composition, structure and function, which all are determined by its biodiversity. The human society receives a flow of ecosystem services from the ecosystem, which contribute to the prosperity and well-being of its members.

Ecosystem Services can be divided in three main categories: provisioning, regulating and cultural services. The **provisioning services** consist of the material flows, like agricultural crops for food, wood for construction, biomass for energy or drinking water. **Regulating services** are those that provide environmental protection like erosion control, air cooling and filtering by vegetation or climate mitigation through carbon uptake and storage in forests, peatlands and soils. **Cultural services** include the diverse spiritual, recreational and scientific experiences ecosystems provide to humans. All these services directly depend on biodiversity.

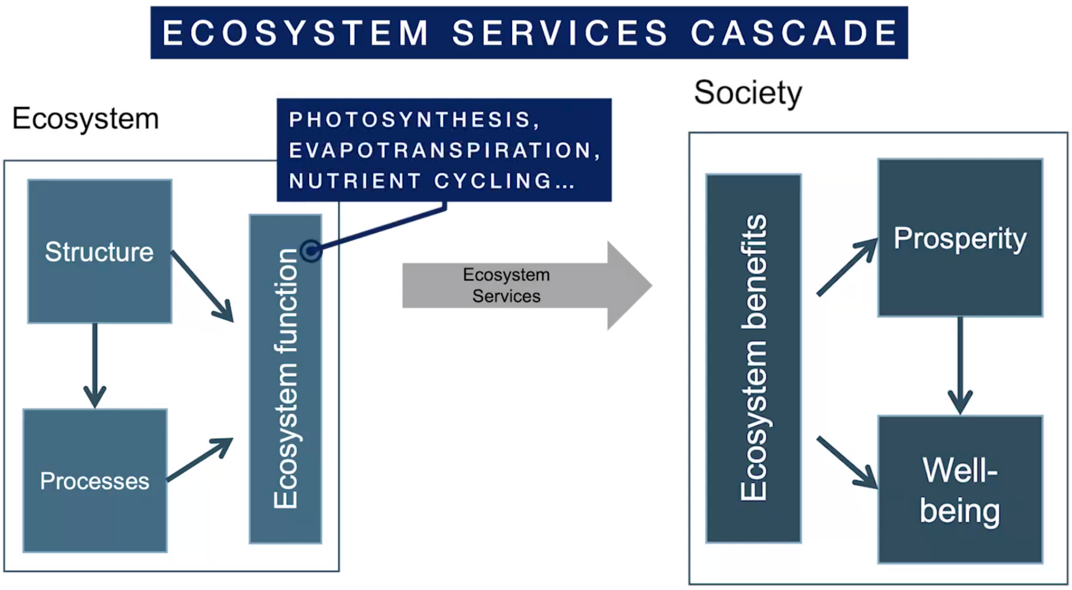


Figure 9: Ecosystem Services cascade

There is a **positive but asymptotic** biodiversity – ecosystem service relationship. This relationship is visualised in Figure 10. This means that increasing biodiversity leads to an increase in ecosystem service performance up to a certain extent, after which adding more biodiversity does not much further increase the service provision. It also means that losing some biodiversity as a consequence of human ecosystem degradation may not directly lead to large losses in ecosystem services, but that a further degradation over a critical threshold of species loss will lead to strong reductions in ecosystem services.

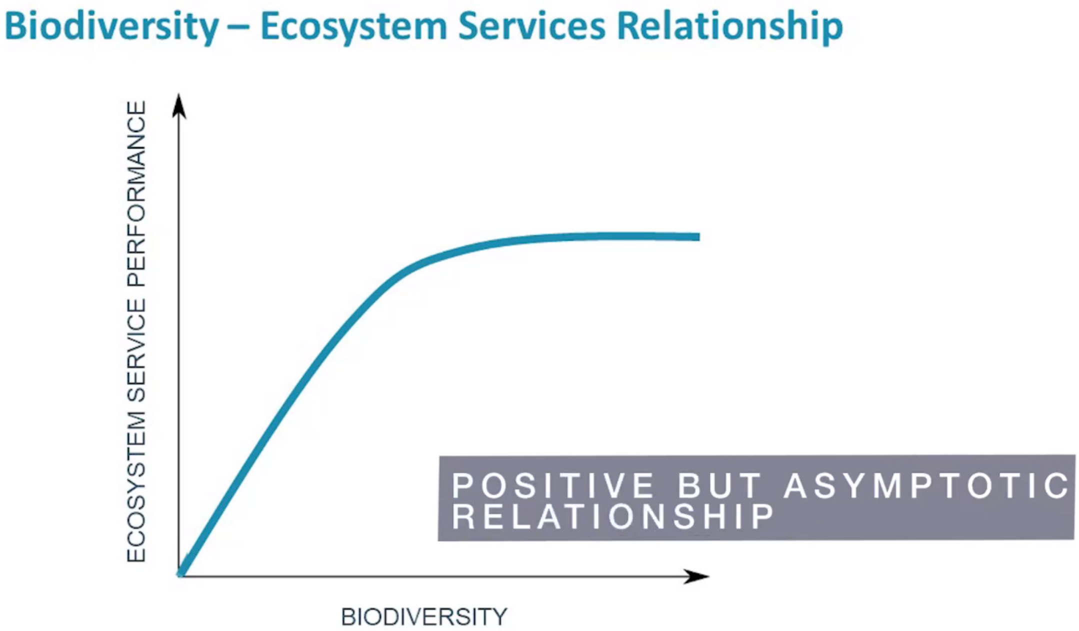


Figure 10: Relationship between biodiversity and ecosystems services

Nowadays, IPBES, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, speaks about **Nature's Contributions to People (NCP)**, which are all the contributions, both positive and negative, of living nature, which includes the diversity of organisms, ecosystems, and their associated ecological and evolutionary processes, to the quality of life for people.

2.5 How to measure biodiversity and what are the challenges

2.5.1 Challenges

To directly measure the effect of a human intervention on the level of biodiversity, we require evidence of a clear **causal relationship** between intervention and impact (change in biodiversity is caused by the human intervention), the **absence of other confounding factors** (human intervention the only thing that is influencing) and clear decisions on **which elements of biodiversity** are considered.

Hence, measuring and monitoring biodiversity is very complex. For this reason often simplified proxies for biodiversity are used, e.g. **indicator species**, which are known to be sensitive for certain human-induced disturbances, or **multi-taxa approaches**, to sense the impact on different groups of organisms. Measuring the different dimensions of biodiversity requires a combination of different techniques from regional coverage using satellites to local ground coverage using camera traps or citizen science.

In order to create some structure in this multitude of information, the international community (GEO-BON) developed a framework of Essential Biodiversity Variables (EBV) including the following classes: **genetic composition, species populations, species traits, community composition, ecosystem structure and ecosystem functioning**.

2.5.2 Measure biodiversity

Monitoring species population is today the most common indicator method. Observations from experts and citizen science are brought together in the GBIF global biodiversity database. This data together with other data sources are used to build and update **IUCN Red List**, visualized in figure 11, as the major indicator tool for global biodiversity loss.

This indicator tool monitors the extinction risk of individual species. Based on objective criteria, species are assigned to one of the 6 classes in the red list going from least concern for species with the lowest risk of extinction to species that are globally extinct. The individual species status information can then be brought together synthesis indices, like WWFs **Living Planet Index** (LPI). As explained in figure 8.

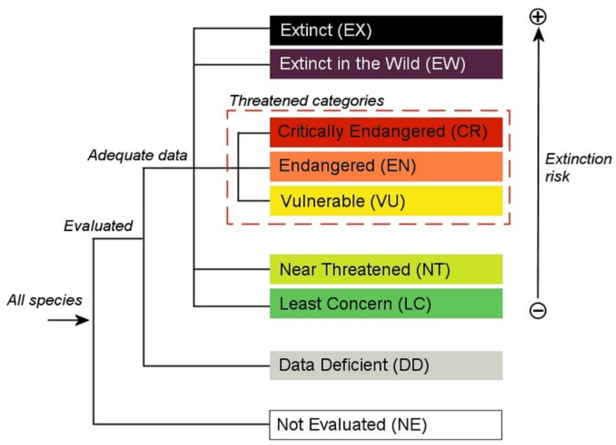


Figure 11: The IUCN Red List - indicates how close a species is to becoming extinct

A very different approach is to measure so-called **mid-point indicators**. They do not measure the biodiversity loss itself, but rather quantify the frequency and intensity of the damaging interventions. These indicators assume a known relationship between intervention and effect, which is a rather rough approach. Their advantage is that they are much cheaper and have much better data availability than measuring biodiversity effects itself. Examples are area impacted by irrigation, fertilization, biocide use,... .

This approach is typical for **Land Use Impact methods** used in **LCA (Life Cycle Assessment)** and **Environmental Footprint Analysis** , which calculate the impact of land use change (e.g. deforestation) or of permanent land use (e.g. long-term cropland) by measuring the loss of land quality over time for a certain area, see figure 12. (Land use change → Strong decline in small period & Permanent land use → less strong decline for a long period)

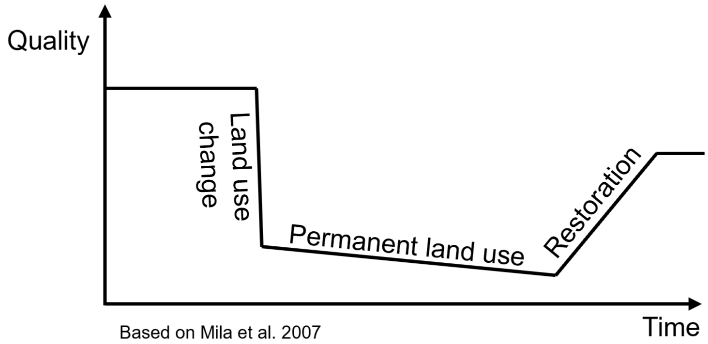


Figure 12: Evolution of land quality with land use interventions

2.6 Treats for biodiversity

The main threats to biodiversity can be categorized in 5 different drivers, referred to as the **evil quintet**. In decreasing order of importance these are habitat loss, overexploitation through hunting and fishing, climate change, pollution and invasive species. Apart from these threats there are other threats that do not fit clearly into these categories, such as for example wildfire or direct human disturbances due to recreational activities.

Habitat loss refers to the transformation of natural habitats into other land uses. It is mainly caused by expanding agricultural land which is especially problematic in the tropics and subtropics.

Overexploitation through hunting and fishing is the second most important threat. It can happen for food or for valued body parts such as ivory.

Climate change is a newly emerging threat to biodiversity. The climate can become too hot or too dry for a species to persist. And very often northward migration of the species to a more mild climate is hampered through habitat loss.

Pollution mainly refers to the effects of agrochemicals such as pesticides and the effects of overuse of fertilizers.

Invasive (or exotic or non-native) **species** may outcompete or predate the indigenous species. They can also introduce new diseases and pests. This as opposed to **indigenous** (or native) **species**.
Invasive alien species (IAS) are non-native species that cause economic or environmental harm or adversely affect human health.
Alien species can be introduced in many ways. Usually we divide them into **unintentional/accidental and intentional introductions**.

2.7 Restoring biodiversity

There are a couple ways we can try to conserve and restore biodiversity. It is based on the idea that there are two main ways to reduce the impacts of farming on wild species. The first is making the farmland itself more wildlife-friendly (this is land sharing), the second is making more space for natural or unfarmed habitats (this is land sparing).

Land sharing or nature friendly farming (left on Figure 13) involves integrating practices which benefit biodiversity (such as retaining important habitat features like ponds and hedges) within the area producing the food. There is however a limit to how friendly one can make farmland for wild species without reducing the yields too much, and lower yields mean that more land is needed to produce each ton of food, making it harder to create more space for nature.

Land sparing on the other hand (right on Figure 13) starts from the observation that high-yielding agriculture can reduce the area needed to meet a given level of demand for food. Land sparing will concentrate higher-yielding production in some parts of the landscape while simultaneously retaining or restoring other parts of the landscape for nature.

When studying this model, the key finding is **that most species would have larger populations if a given amount of food is produced on as small an area as possible, while sparing as large an area of native vegetation as possible**.

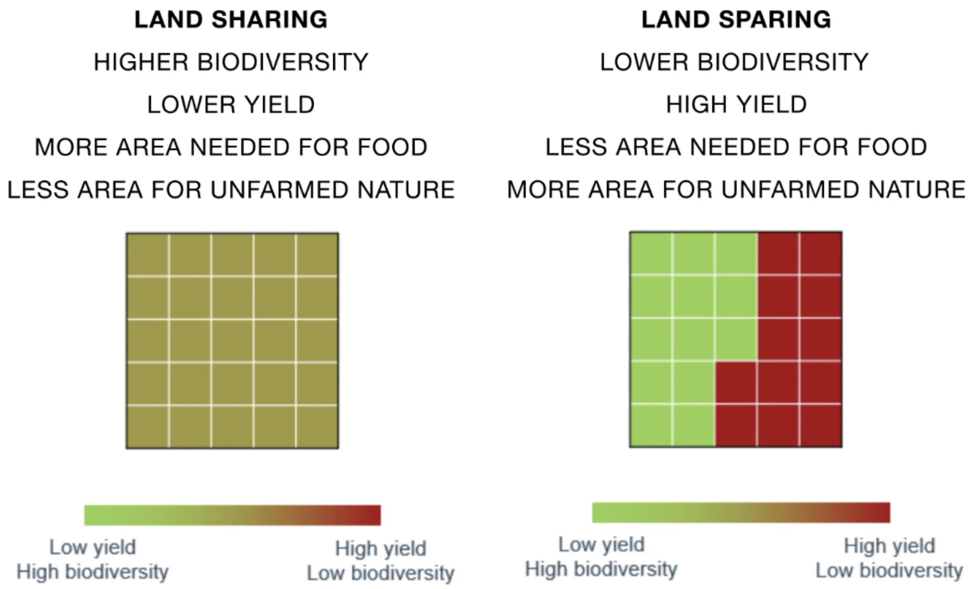


Figure 13: Land sharing versus land sparing

A second subject we can study, is human activity. **Ecological restoration** is the process of **assisting the recovery of damaged, degraded, or destroyed ecosystems**. Restoration aims to reverse damage and protect the biodiversity and services that ecosystems provide.

Recently, **rewilding** has emerged as a new approach to ecosystem restoration. It promotes "wild, autonomous" nature, with natural processes driven by keystone species and abiotic processes leading the way instead of human intervention. Some examples of common approaches employed in rewilding initiatives are the **reintroduction of large fauna species or trophic rewilding, restoring habitat connectivity, wetland restoration and natural regeneration and succession**.

3 Demography

3.1 Study guide

Module 3 (Demography) sketches basic insights into the origins and dynamics of population growth. Make sure to understand:

- The link between the industrial revolution and evolutions in mortality
- The drivers behind the evolution of fertility rates
- The link between evolutions of mortality and fertility
- How evolutions of mortality and fertility influence both the demographics and the economic growth expectations of societies

Don't learn the specific examples by heart; focus on understanding the reasons behind the evolutions.

3.2 Link between industrial revolution and evolution in mortality

The spread of the **industrial revolution** was **paired with** a **decline in mortality**. The reason behind this is that the industrial revolution led to a completely different societal development.

Before the industrial revolution, most people would produce their goods locally at home and they taught their kids their trades. This changed in the industrial society. People moved to the city and capital became a much more important production factor as production became concentrated and factories had to be built. The people with capital, they need new knowledge, new insights to make their factories more efficient, to make new products, and therefore, they need science and technology. This science and technology will not only be used to make their factories more efficient, but it will also be used to reduce mortality, to have better food, to have new food storage techniques, etc.

So, this evolution resulted in a totally different society that was developing rapidly and the combination of increased knowledge (a deeper understanding of technology, production methods, and various industrial processes), increased understanding (a better grasp of health issues, living conditions) and a different societal organization (shift from a rural society to cities) also led to a dramatic reduction of mortality rates.

3.3 Drivers behind the evolution of fertility rates

There are a lot of drivers behind the evolution of fertility rates.

- **Reduced Child Mortality:** With improvements in healthcare, sanitation, and overall living conditions, child mortality rates drastically decreased. Parents no longer needed to have a large number of children to ensure that some would survive to adulthood.
- **Social Welfare Systems:** The emergence of social welfare systems, including healthcare and pensions, meant that elderly individuals were no longer solely dependent on their children for support. This reduced the need for large families to ensure care in old age.
- **Educational Investments:** Industrial societies placed a higher value on education. Parents began investing more time and resources in the education of their children, aiming for quality rather than quantity.
- **Wealth of a country**: Wealthier societies have less children
- **Marriage age**: In societies where women marry later, they have less children.
- **Changing parental priorities**: Parents, particularly those with careers and personal aspirations, prioritize investing in their own development. As a consequence, they tend to have fewer children, as raising children requires significant time and financial investments.

- **Education of women**: If women are educated, they are better capable of applying of using contraception correctly. If you use contraception correctly, then you will end up probably with less children. It is also true that if you offer education to women, then of course they need to invest time in that and very few people have children while they study. Also, after their studies, these women very often want to have a job and pursue a career. Because of that, they will have less time to care for children and if there is less time available, that will also lead to having less children. The desire to provide their children with equal or better opportunities than they had further accelerates the decline in the number of children.

3.4 Link between evolutions of mortality and fertility

In general the decline of fertility starts decades after the decline of mortality. Society has to adjust to a higher life expectation before this higher life expectation translates into a lower number of children being born. The only exception to this rule is France in the end of the 18th century where mortality and fertility started to decline at the same time. Scientist suggest that there is a link with the French Revolution.

The delay between child mortality decline and fertility decline leads to a population increase . The increase of population is higher in developing countries because the knowledge to reduce mortality was already much more developed by then. This can be seen in figure 14.

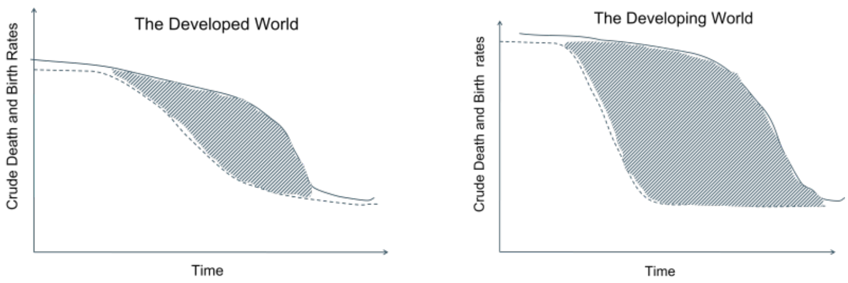


Figure 14: Fertility and mortality decline in the develop(ed)(ing) world

3.5 Influence of mortality and fertility evolution on the demographic and economic growth expectations of societies

When there is a decline in mortality, followed by a decline in fertility, there will first be a phase where there are a lot of young people and fewer older people. This is an important phase in the economic development of a society because there are a lot of people wo can produce and contribute to economic growth, while they do not need to take care of a lot of older people. This can result in an economic growth of 7 to 10% per year during several decades. This growth does however require the right conditions for economic development, with education as its key factor.

This growth will however come to an end. When the mortality and fertility keep declining, there will be a moment when there are a lot of older people with less youngsters. Hence, there will be less people to contribute and more people to take care of. These mature societies will keep growing, but at a much slower pace then before, maybe 1 to 3% per years. There could be even years where there is no economic growth.

4 Energy

4.1 Study guide

- What is energy?
  - Understanding the meaning of the first and second law of thermodynamics in energy production
  - Knowing the concepts of energy, power, energy vectors, energy balances and energy systems
- Thermic energy sources
  - Recognizing primary and secondary sources of energy
  - Understanding the link between energy production and climate change
  - Knowing the principles of combined cycle power (CCPP) and combined heat and power (CHP)
  - Having an idea of orders of magnitude and efficiency of the different production technologies
  - Knowing the different types of gas used in the energy system
- Renewable energy sources
  - Understanding the basic principles of renewable energy production
- Energy cost
  - Knowing the concepts LCOE, dunkleflaute and duck-curve
  - Understanding the consequences of unbalances between production and consumption
- Energy networks
  - Understanding the difference between the meshed high voltage grids and local radial distribution grids
  - Understanding the added value of adding a communication layer to the energy networks
- Energy efficiency
  - Having an idea of the relative parts of industry, transport and built environment in energy consumption
  - Understanding the direct and indirect rebound effects of energy saving measures
- Energy consumption
  - Understanding how the energy consumption can be organized more sustainable
  - What might be the role of hydrogen?
- Energy storage
  - Understanding the key role of lithium batteries in the energy transition
  - Knowing different storage technologies
- Energy markets
  - Understanding the difference between old and new tarriff schemes for energy
- Energy policies
  - What is the emission trading system?

4.2 What is energy?

Energy is what causes change in the physical sense: for instance, you can do work or heat something up, or cause a chemical reaction. Energy is expressed in Joules [J]. When we want to explain how much energy is converted per time unit, we talk of **power**, expressed in Watt (Joules per second).In many practical applications the unit kWh is used: this is the amount of energy converted by an application with a power of 1 kW, if it would run for 1 hour. **Energy vectors** can be defined as the forms of energy, for example heat present in warm water or steam, electricity and chemical energy.

In principle, energy cannot be destroyed nor created, it will always be converted in some other form. These conversions will not always be useful or desired. This is know as the **first law of thermodynamics**. Furthermore, some energy conversions can happen in the two directions: think of the battery in your mobile phone that can be charged and later discharged. Other conversions can only happen in one direction, for instance, you can burn a fuel to run a combustion engine in a car resulting in kinetic or motion energy, but you cannot recover the fuel as such when you slow down again. This follows from the **second law of thermodynamics**.

Engineers usually talk about an **energy system**. This can be your home: you import energy like electricity or gas, to be converted into an energy service or end-use like lighting or heating. This is a simple example of an **energy balance**. The amount of energy that is consumed equals the imported energy, of course plus some losses. When we zoom out, such energy balances can be drawn up for an entire country: typically, oil or gas, or perhaps coal is imported.

4.3 Thermic energy sources

Primary energy sources are found in nature in a stable form: for instance, oil, coal or sun light. **Secondary energy sources** do not occur in a stable natural form, but are created by conversion of a primary source. Electricity or hydrogen, so-called energy vectors, belong to this category. They might exist in nature – think of a lightning strike – but are not stable or concentrated enough to be usable.

Some of these energy sources are renewable. Fossil fuels are not. These **fossil fuels**, typically in the form of coal, oil or gas, could lead to sustainability issues. Combusting them rises the CO2-levels in the atmosphere, thereby **contributing to climate change**.

The laws of thermodynamics will tell that the **conversion from energy sources into a usable form**, think of refined fuel such as gasoline or electricity, **will generate losses**. As a consequence, the total **efficiency is less than 40%**, meaning the majority of the primary energy is turned into useless heat rather than electricity. Gas power plants look pretty much the same. However, the modern ones are so-called **Combined Cycle Power Plants (CCPP)**. They first use a compressor-combustion chamber-turbine combination which is similar to aircraft engines, but then with an electrical generator attached. The exhaust gases are hot enough to pass through a boiler after which electricity is generated with the steam cycle. The combination of these two machine sets lifts the **total efficiency up to 55 to 60%**. An additional benefit is that these are much more dynamic and can change their output power rapidly.

Such combined cycles are used in other applications as well, under the name **Combined Heat and Power systems (CHP)**: for instance, many industrial processes in the food or chemical industry need a lot of high-temperature heat. By combine an electricity generation cycle with an exhaust temperature close to the process temperature, a **very high total efficiency** can be obtained.

The **traditionally used gas** in these conversions is natural gas, containing fossil-based **methane originating from gas fields**. This methane can be extracted **from rocky layers**, but also **from biological processes** like fermentation, of for instance **specifically grown plants or organic waste**, coming from agriculture, food industry, etc. Finally, gas **can be made synthetically through a chemical process** starting from hydrogen and a carbon source.

4.4 Renewable energy sources

It is possible to convert **direct or scattered sun light** directly into electricity using so-called **photovoltaic**, in short "PV", **cells**. Another form of weather-driven electricity production uses **wind** to drive large free-standing **turbines** with a build-in electricity generator. For completeness, we should also mention **hydropower**-based electricity production, which is in principle operating renewable and carbon-emission free as well. This kind of power plants use giant **dams** to withhold water on a river or a large difference in height in a mountainous region. By releasing the water through a turbine-generator combination, electricity is produced.

4.5 Energy cost

To make a fair comparison between the costs before and after the construction phase, the so-called **Levelized Cost Of Electricity (LCOE)** can be used. This allows to include all these costs over the whole lifetime of the installation on a common basis and average them over the produced unit of electrical energy. It can be noted that **most technology become cheaper when they mature**, the so-called learning curve. This can be seen in figure 15.

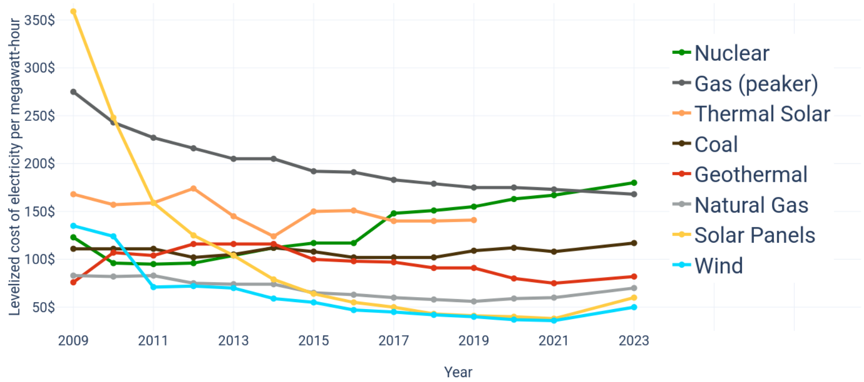


Figure 15: Levelized cost of electricity over the most recent years

In a system with many weather-related renewable sources like solar power, there is an obvious difference between the middle of the day, when there is abundant sun and the night. Because of the unbalances between production and consumption, the transition in between asks for a lot of alternative power sources to come on line. These can be batteries, other controlled power plants, or exchanges over the electricity grid with connected regions. This is depicted in the so-called **Duck Curve** (figure 16).

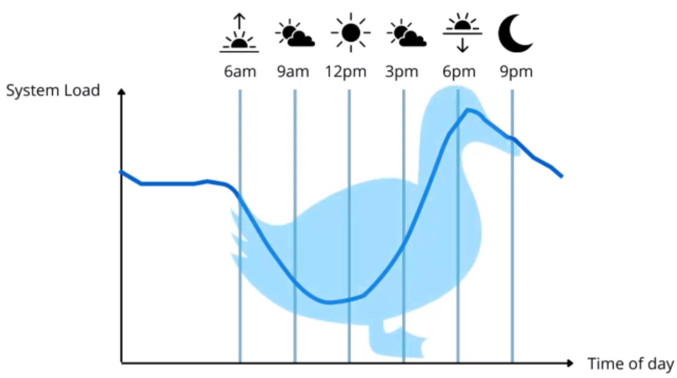


Figure 16: Duck Curve

If we zoom out over a series of days, we have to account for cloudy days with for instance less wind. These are often referred to as **Dunkelflaute**, a German word. In practice also here the solution is a mix of generation technologies and international energy exchanges.

4.6 Energy networks

For the transportation of energy between end consumers, networks are needed. At the highest level, you find the electrical transmission grids. This can be in the form of **high voltage lines**, underground cables or even cables through the bottom of the see. When you look at the map of a high voltage system, you will see that **these lines form large meshes**. Every substation is connected through multiple high-volt slides.This is done **to increase the reliability**.

At a more local level, you will find the **local distribution grid**. In most countries, this is built with a system of underground cables under the streets. Contrary to the high voltage grid, the topology here is **radial**. In the distribution grid, multiple voltages are used. In the last part closest to your home, a transformer will step down the voltage to a safe level, which can be brought inside your house.

These days, it is almost impossible to run all those **energy networks** without digital tools for **management or protection**. Therefore, the **presence of a dependable communication system is a necessity**. In fact, the whole energy system is a so-called system of systems.

4.7 Energy efficiency

In most European countries, roughly **1/3 of the energy** will be **consumed in industry** and **1/3** is **needed for transportation**. The **rest** is **used in the build environment**, for energy services like heating and lighting.

When we consider energy consumption we want this to be as efficient as possible. Unfortunately replacing an energy-consuming device with one that is, as an example, 10 times more efficient, will not result in an overall 10 times lower energy consumption. The explanation for this is found in the so-called **rebound effects**: when you give people a more efficient device for instance and a led lamp, they tend to let it burn longer, compensating about 20% of the possible savings. This is the so-called **direct rebound**. There is also an **indirect rebound**, accounting for about 10% of the possible savings, which is explained by the fact that you will save money which you spent on other energy consuming goods. This is visualized in figure 17.

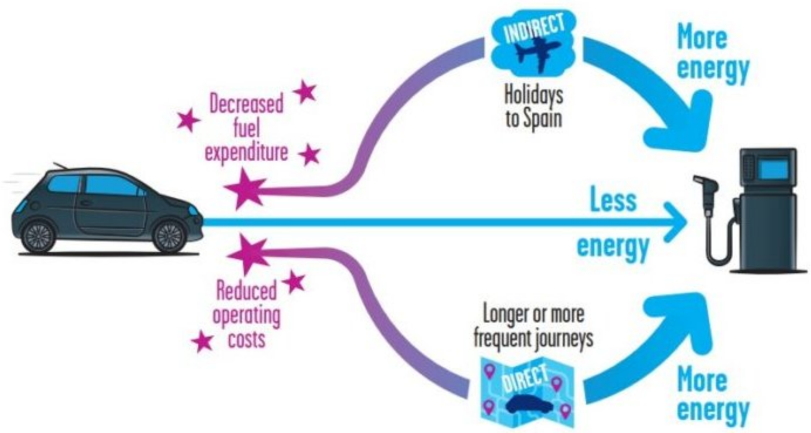


Figure 17: The Rebound Effects

4.8 Energy consumption

There are multiple ways the energy consumption can be organized more sustainable. For instance, there are more and more **photovoltaic panels** on our buildings. This means we can produce a lot of electricity locally and store the excess of produced energy in home batteries. Furthermore, newly available technology like the **heat pump** is a much more effective way to heat buildings. When using heat pumps, 3 to 5 times less energy is needed and CO2 emissions will be reduced significantly. The rise of electric vehicles in favour of fossil fuel driven cars also results in more sustainability.

When we look at the usage of natural gas and fossil fuels, we might consider dropping them and using a more sustainable alternative like **hydrogen** instead. However, the problem with hydrogen is that it needs **a lot of consecutive conversions** to produce it and make it usable for the end consumer. Because of the conversions, there are **a lot of losses over the whole chain of processes**. This makes the hydrogen route **5 to 6 times less efficient** than the direct electric route with heat pumps. Therefore, this isn't a suitable alternative at the moment, except for long distance transport, such as long range shipping or airplanes.

4.9 Energy storage

Although batteries already exist for many decades, one could say that the relatively recent **lithium battery should be considered as a key enabler of the energy transition**. Mass production of batteries brought down the price of lithium batteries with a factor of 10 in the last decade. Such lithium based batteries have the advantage that they **can be charged and discharged hundreds even thousands of times without significant reduction in capacity**. They are also very compact and have therefore **high energy and power density**. Lastly, modern types of lithium batteries are also **fully recyclable** and don't contain cobalt anymore.

Batteries are a great solution to balance production and demand of electricity over a relatively short term being within a day or over the course of a week. However to balance energy over a longer period, for instance, between seasons, **other forms of energy storage** are needed. For this purpose, **thermal storage** or **pumped hydro storage using large water basins** are applicable.

4.10 Energy markets

Since the turn of the century, in Europe, the electricity and gas market, evolved towards a so-called "free" market, with **energy prices** being **determined by offer and demand within a market system, rather than fixed up front**. In the past we just paid for the energy consumed: the kilowatt hours of electricity, the liters of fuel or the cubic metres of gas. However, this is changing.

With the availability of renewable energy sources like sun or wind, which are produced at almost no production cost, it is mainly the investments that are driving the price. In addition, the energy grids, more in particular the electricity grid, are stressed much more. Therefore, **the newer electricity tariffs are rather driven by the capital costs than the operational costs**, and we see a **shift from bills based upon kilowatt hours to capacity-based charging**.

4.11 Energy policies

A series of European directives have been developed: they form the basis of the energy markets, set the goals for energy efficiency measures, and the decarbonization.

The **emission trading system (ETS)** is an example of this. The idea behind this is to award tradeable rights to emit CO2 and to set clear goals to significantly reduce this by the middle of the century. In this way the technologies that can mitigate CO2 emissions in the most economic way will be favoured. In practice this works like a carbon tax, which is included in the price of electricity or industrial products.

5 Raw materials and circular economy

5.1 Study guide

Make sure to understand:

- Meaning of the terms (non-)renewable resources, (in-)finite resources, critical materials
- The drivers of material demand (i.e. understand the I-PAT equation and past and predicted evolutions of the constituent factors), including also influence of the energy transition on predicted material demand
- Different types of scarcity, including examples
- Potential caveats of using bio-based materials
- Order of magnitude of waste produced and of importance of waste treatment strategies
- Waste hierarchy
- Scope of the Basel convention
- The importance of resource demand in terms of environmental impact (climate change, water stress, biodiversity).
- Strategies to reduce climate impact of steel and cement production (= materials with highest cumulative contribution to climate change)
- Life Cycle Analysis: what is the meaning of the 4 main phases (goal and scope, inventory, impact assessment, interpretation), the concept of "functional unit"; and what is the difference between an emission, an impact category (= mid-point) and a damage category (= endpoint)
- Difference between relative decoupling and absolute decoupling
- Circular economy strategies
- Reasons why recycling is not going to solve all material resource related problems
- Difference between Direct Material Consumption and Material Footprint
- Links with other challenges

5.2 (Non-)renewable resources, (in-)finite resources and critical materials

For **non-renewable resources**, there is a certain amount available for extraction in reserves, but this amount will run out over time. **Renewable resources** on the other hand can grow back, if they are extracted or harvested at a rate that is lower than the time they need to grow back.

Infinite resources are resources we can never run out of, regardless of the extraction-rate. This is not the case for **finite resources**.

To further clarify the differences, here are some examples:

- Renewable and infinite resources are air and wind, seawater.
- Renewable but finite are for example biomass and fertile soil, drinking water.
- Non-renewable and infinite, or better said abundantly available, are some metals and minerals such as bauxite and iron ore.
- Non-renewable and finite are other metals, such as tin (Sn) or lead (Pb), indium (In), and fossil fuels.

A **critical material** is any substance used in technology that is subject to supply risks, and for which there are no easy substitutes

5.3 Drivers of material demand

There are three factors that drive the evolution in material demand: population, affluence and technology.

Population represents the number of people on the globe. The population will continue to keep growing, and paired with this grow is a higher demand for materials. However, the annual growth rate of the world population is decreasing so **the importance of population growth in the evolution in our material demand will also decrease** in the future.

Affluence represents the average level of wealth per person, often expressed as the GDP - gross domestic product - in dollar per capita. **The worldwide growth rate of GDP per person** has **remained rather constant** over time. Because of this, we can extrapolate these numbers for the foreseeable future.

The last factor represents the contribution of **technology**, specifically how material-intensive our economy is and how many kg of material we need per dollar of GDP. We can see that industrialized countries have a higher material footprint and a higher GDP than average. If we look at this relatively however, **though their total material footprint still increases, their relative material footprint per dollar of GDP decreases**. This is not the case in rural societies who are still experiencing a transition to an industrialized society. The reason behind this is that maintaining something is less material intensive that developing something and there are innovate inventions by scientists and engineers, who develop new technologies that require less material.

The **I-PAT** equation (figure 18) measures the 3 factors, i.e. population, affluence and technology, that affect the environmental impact.

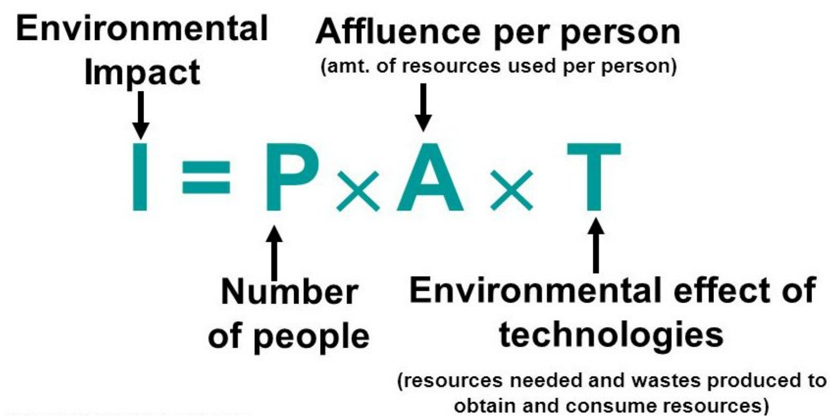


Figure 18: the I-PAT equation

In the last 30 years of the 20^{th} **century**, population growth was important; affluence growth was important; but the material demand per dollar declined slightly (due to the servitization). **In the past 20 years**, we have seen a slower population growth, a similar affluence growth, yet an increasing material intensity per dollar (because upper-middle income countries have transitioned through the material intensive phase of industrial development). **In the future**, population growth will continue, but will become less important in this evolution; affluence will continue growing; and the material demand per dollar will continue to grow, bt not faster, and faster, and faster...

If we look at the reasons behind material demand, we can conclude that the demand will continue to keep growing. This growth will not be equal for all material types. Consider for instance materials needed for the **energy transition**. Scientists are expecting significantly higher growth rates because of the transition to a carbon neutral energy supply. Lithium for instance, for producing batteries, or for rare earth elements, that we use in magnets for electric vehicles and windmills.

5.4 Different types of scarcity

Absolute scarcity is when the amount of raw materials within these reservoirs can only cover the demand for that material for the coming decade or two. There can be a couple reasons for this. First and foremost, the most easily accessible and richest raw materials do deplete. **The quality of raw materials is often decreasing**. By quality, we understand here the concentration of useful elements they contain. **Copper** ore, for example, contained 3% copper at the beginning of the last century; today it contains a good 0.3%. So, ten times as much copper ore has to be mined for the same amount of copper. Moreover, the new deposits that are found are often difficult to access.

If we divide the **current reserve by the current demand**, we see how many years are still left. This is called the **static depletion index**. However, demand for raw materials changes, for most materials it increases. When we take the **predicted change in demand into account**, we call this the **dynamic depletion index**. For a resource with an increase in demand, the dynamic index will be smaller than the static index. An example of this behaviour is the depletion index of Copper (figure 19).

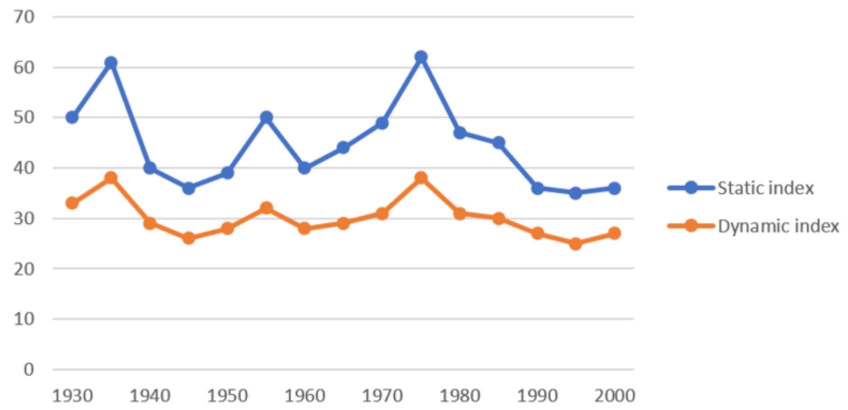


Figure 19: Static and dynamic depletion index of copper

The **depletion index remains rather stable**. This can be contributed to the finding of new reserves and the improvement of extraction technology.

A second aspect of scarcity is that some ores are **concentrated in only a limited number of countries**. **Lithium** for example, needed for batteries for electric vehicles, today comes mainly from Bolivia, Chile and Argentina. **Cobalt** and **tantalum** are found in Central and South Africa, rare earth metals are mainly mined in China. These ores do not necessarily come from politically stable regions. Regional conflicts can have a major impact on the global price of the raw material. We say such materials are **economically or geopolitically scarce**. For example, China used an embargo on rare earth exports as an economic threat during the dispute with Japan over the Senkaku Islands in 2010. As a result, the price of some elements, e.g. neodymium, increased a tenfold in a matter of months.

Finally, a third scarcity problem is that quite some more exotic elements, often used in high-tech applications, cannot be mined by themselves. They occur in small quantities as a by-product of ores of other metals, called carrier metals. **Indium**, for example, is found mainly in zinc ore. However, that ore contains three thousand times more zinc than indium. We therefore say that indium is **structurally scarce**. Two other examples are **Germanium** (produced from sphalerite, silver, lead, and copper ores) and **Gallium** (by-product during the processing of bauxite).

5.5 Potential caveats of using bio-based materials

There are a number of caveats related to the use of bio-based resources. Cultivated or growing **biomass needs land area**. The land used to grow maize, for example, from which PLA plastic can be made, cannot be used for other crops. A competition may arise between the use of land for materials or for food. Furthermore, soil can become exhausted if used too intensively, and there also will be a impact on biodiversity if new land is cultivated for new crops for materials.

Also typical of agriculture is **the use of fertilisers and pesticides**, which can make the environmental impact of bio-based materials significant.

Other concerns are about the **water and energy needed**. Some crops for raw materials, for example cotton, require a lot of water during cultivation. Most crops also require quite a bit of additional energy for tilling the soil, harvesting, and so on. Some new types of bio-based plastics even require more energy and more CO2 emissions to make them than an equivalent conventional petroleum-based plastic.

We can conclude that replacing non-renewable materials by bio-based materials is promising, but the impact throughout the entire life cycle has to be carefully investigated.

5.6 Waste

5.6.1 Amount of waste produced, importance of waste treatment & Basel Convention

The world generates more than 2 billion tonnes of municipal solid waste annually. In 2020, an amount of 2.24 billion was estimated. The **amount of waste production is different in each country** and is mainly related to their income levels. **Municipal solid waste** includes household, commercial and institutional waste. The composition of such waste is **very heterogeneous**.

The **two biggest waste streams** when it comes to solid waste are **electronic waste** and **plastic waste**.

Electronic waste contains a **mix of materials**, including **toxic substances**, and often **contains valuable resources**. It is **one of the fastest-growing waste streams globally**. However, it is not always managed correctly, and often is exported to developing countries where it is managed in uncontrolled and unsafe ways. To address this issue, **the Basel Convention** was established to **ensure sound environmental management** of electronic waste and to **prevent its illegal export** to those countries.

Plastic waste ends up in **landfills, is incinerated or is mismanaged**. Nearly 80% of all **ocean waste consists of plastics**. Over time, this **plastic degrades into micro-plastics**. **The Basel Convention** extended its reach to address plastic waste. This includes a set of actions aimed at preventing and minimizing plastic waste production, and ensuring environmentally sound management practices.

Considering the huge amount of waste generated worldwide, **waste minimization and management are key for a more sustainable development**.

The current trends in waste generation and management have **significant environmental, social, and economic impacts**. If you think of the more than 2 billion tons of waste produced, over **30% of this waste is still not managed** in an environmentally safe manner. This has a lot of negative impacts like a loss of resources, as well as to different environmental and health impacts due to soil and water contamination, and air pollution. For example, **solid waste is responsible for 3% of global greenhouse gas emission**. Furthermore, the **degradation of organic waste** in landfills (and open dumps) **generates a gas composed mainly of carbon dioxide and methane**. Another example is that **waste releases hazardous emissions** and particular matter into the air **when it is burned in an uncontrolled manner**, causing significant health issues. Lastly, **unmanaged waste degradation** can result in the creation and **runoff of leachate**, a hazardous liquid that can contaminate water bodies and soil, leading to the contamination of, for example, drinking water, and transmission of diseases.

5.6.2 Waste hierarchy

In Europe the European Commission defined the **waste hierarchy** as a guiding principle for sustainable and integrated waste management. It ranks waste management alternatives based on their potential to minimize environmental impacts, health risks, and promote the recovery of resources.

At the top of the hierarchy, waste prevention should be prioritized to minimize waste generation. If prevention is not possible, the focus should shift towards promoting the reuse of materials and components. Recycling follows as the next best solution. When none of the above options are feasible, energy recovery from waste is considered. Finally, landfilling represents the least preferable alternative, and waste disposal should be minimized as much as possible. This waste hierarchy is visualized in figure

Figure 20: European waste hierarchy

To conclude, solid waste management is crucial to reduce the negative effects on the environment and human health, and support the transition to a clean and circular economy by promoting resource recovery.

5.7 Importance of resource demand in terms of environmental impact

Figure 21 shows **the share of global impact of different resource types** (biomass, metals, non-metallic minerals and fossil fuels) **on 4 categories** (climate change, particulate matter health, water stress and land-use related biodiversity loss).

When we look at the impact of the four resource types together, we see that they make up **more than 50% of the total global greenhouse gas emissions** and **more than 90% of biodiversity loss and water stress** with agriculture (biomass) as main driver.

The **climate change** impact of metals in mainly due to the **iron and steel** production and due to **aluminium** production.

Mining of non-metallic minerals, in particular for sand, can have **critical impacts on local ecosystems**.

Fossil fuels contribute considerably to **environmental pollution and especially air pollution**.

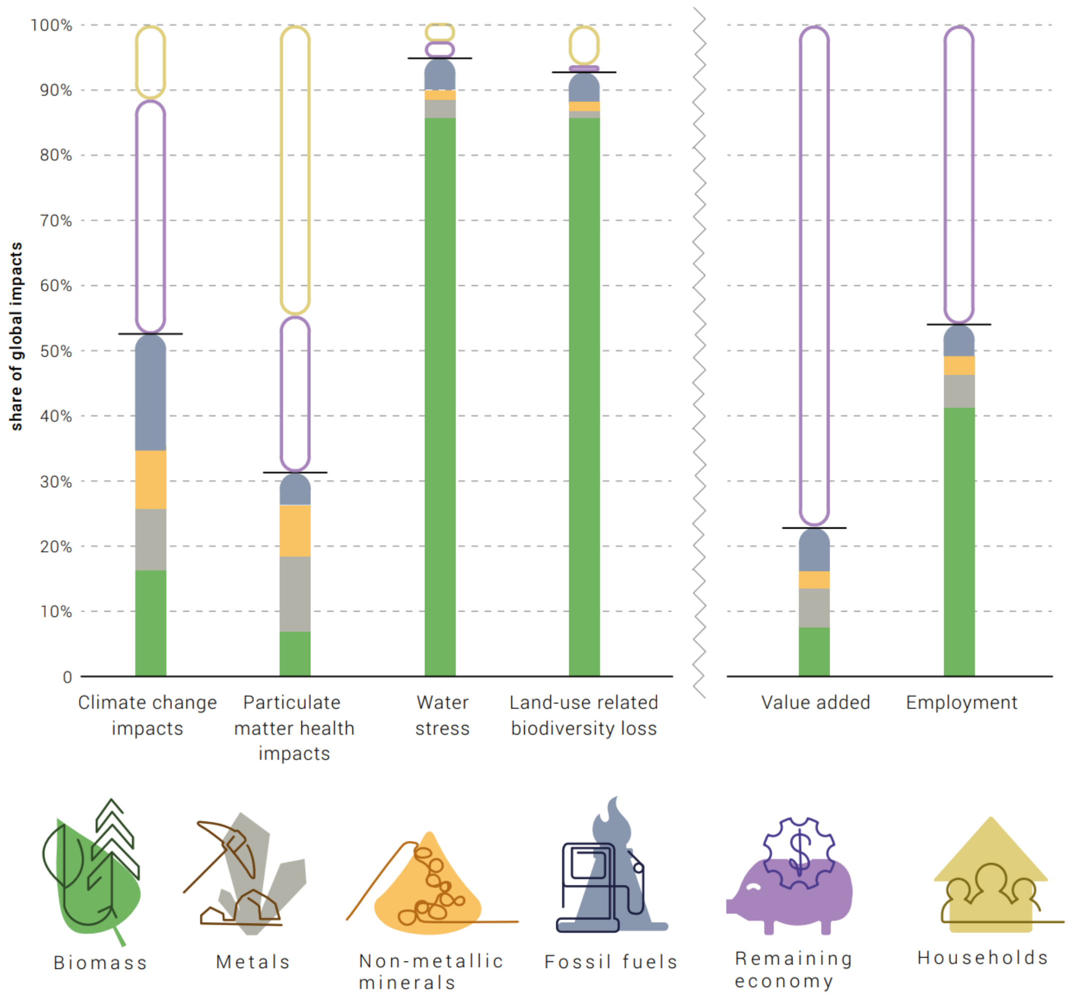


Figure 21: Environmental impact of different resource types

5.8 Reduction of steel and cement productions climate impact

Cement and steel play a large part in the greenhouse gas emission, and it's use is still increasing. What are possible ways to reduce these emissions?

1. A part of the emissions come from the **energy used** during production: Decrease production energy by more efficient processes, and use more renewable energy sources for the energy needed during this production processes.

2. However, there are also emissions related to the production of the material itself. For example, during the production of cement, a chemical process takes place during which CO2 is released. During steel production, cokes are used in the chemical process to extract iron from iron ore, thereby releasing large amounts of CO2.

   A possible solution is **using different resources** during these processes. For steel production this is already possible by using hydrogen instead of cokes. However, this requires large investments in new production processes and infrastructure and the production of hydrogen also requires some energy. Another way to reduce the emission of CO2 is by capturing it before it is released into the atmosphere and storing it (Carbon Capture Storage – CCS) or using it elsewhere (Carbon Capture and Utilization – CCU).

3. A third solution lies in **reusing and recycling of waste**, so that the demand for new materials decreases.

5.9 Emission, impact category and damage category

There are three main **damage categories (end-point indicators)**. Human health, biodiversity and resource depletion. We do not directly affect these categories. These damage categories are indirectly affected through physical and chemical phenomena known as **impact categories (mid-point indicators)** e.g. climate change.

We often talk about CO2, an **emission**, as a cause for climate change, but of course, there are all kinds of other emissions that have similar effects. Think of methane for example. Methane has a much more powerful climate change effect than CO2 by itself. So a kilogram of methane cannot be added to a kilogram of CO2. We will have to take into account its equivalents, its CO2 equivalents. In the case of methane, for example, that's about 23 times more powerful in affecting the climate change effects.

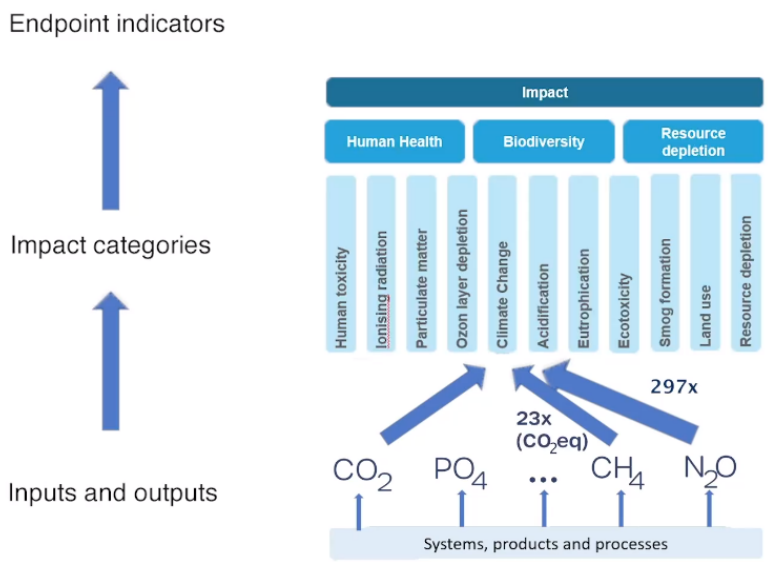


Figure 22: Visualisation on how to measure impact (emission → mid-point → end-point)

In summary:

- First of all, we will need to quantify the inputs and outputs (emissions) from systems, products and processes
- Then, we will learn how to convert those inputs and outputs into impact categories (mid-point categories)
- Finally, these impact categories can contribute to damage categories (end-point indicators) of concern, i.e. human health, biodiversity and material depletion

Fortunately, we have a well-established methodology referred to as **Life Cycle Assessment** to facilitate this process.

5.10 Life Cycle Analysis

Life Cycle Analysis is a tool that allows us to systematically compare alternative design concepts and system designs, based on scientific considerations, when our concern is impact and especially impact avoidance.

There are four main phases in this procedure. The first one is **goal and scope definition**, where you need to very clearly determine what is in and what is outside your study. Secondly, once the boundaries are clear, you go for **inventory**. This can be fairly tedious, sometimes it takes months or even years to collect all the relevant data, but it's indispensable. We have to get through that data collection stage and only then we can come to the actual **impact analysis** where we ask ourselves how much these different ins and outs contribute to the different impact categories that we discussed before. The last phase is the **interpretation**.

The challenge lies in determining system boundaries, such as what is included or excluded, and defining the **functional unit**. A functional unit describes a quantity of a product or product system on the basis of the performance it delivers in its end-use application.

For example:

- When comparing cars, is it normal to compare a two seater to a van that can perhaps contain ten persons, or should you consider five drives by a two seater to have the equivalent functionality as that van?
- When comparing paint, are you going to talk about a litre of paint as the functional unit or are you going to talk about the functionality of covering a wall for a certain period? And perhaps with some quality of paint, you may have to repaint it more often or you may have to apply multiple layers to get the same protection level.

5.11 Relative and absolute decoupling

The concept of decoupling is a strategy put forward by the United Nations, and by the European Commission. The goal is that the need for resources doesn't follow the growth of economy. Decoupling is not only put forward for resource use, but also for the environmental impact. The UN calls it a dual decoupling: the decoupling of resource use from well-being on the one hand, and impact decoupling decreasing environmental and social impacts per unit of resource use on the other hand.

When the need for resources is still rising, but at a lower rate than the economy, we have a **relative decoupling** of resource needs from the economy.

When the need for resources decreases in absolute terms, while the economy is growing, than we have **absolute decoupling**.

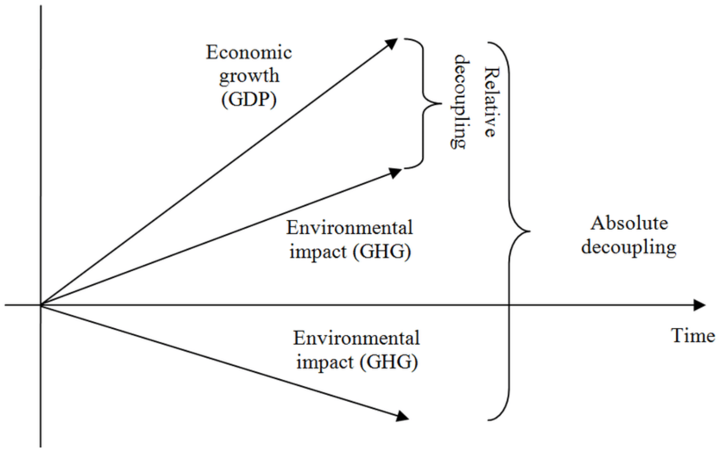


Figure 23: Relative and absolute decoupling

If we look at reality, resource use is decoupled from economic growth in Europe. On a global scale however, there is no decoupling at all between resource use and economy, rather on the contrary (figure 24). This doesn't mean that Europe is doing better than the rest of the world, it depends for example on how the resource use is measured. Here, we took the classical indicator **direct materials consumption (DMC)** as measure.

DMC does not take into account the resources used and wasted in other continents for making the products that are imported. **Only the materials that are physically included in the imported products are accounted for**. Since a lot of basic, resource intensive industry has moved from Europe to other continents, **part of the decoupling is hence due to this move**.

Another way of measuring our materials use is by the **material footprint**, in which all materials consumed in the supply chain to make products, wherever that happened, is included. Typically, the **material footprint for high income countries is higher than the direct material consumption**, and the decoupling of material footprint from GDP or economic growth is less obvious.

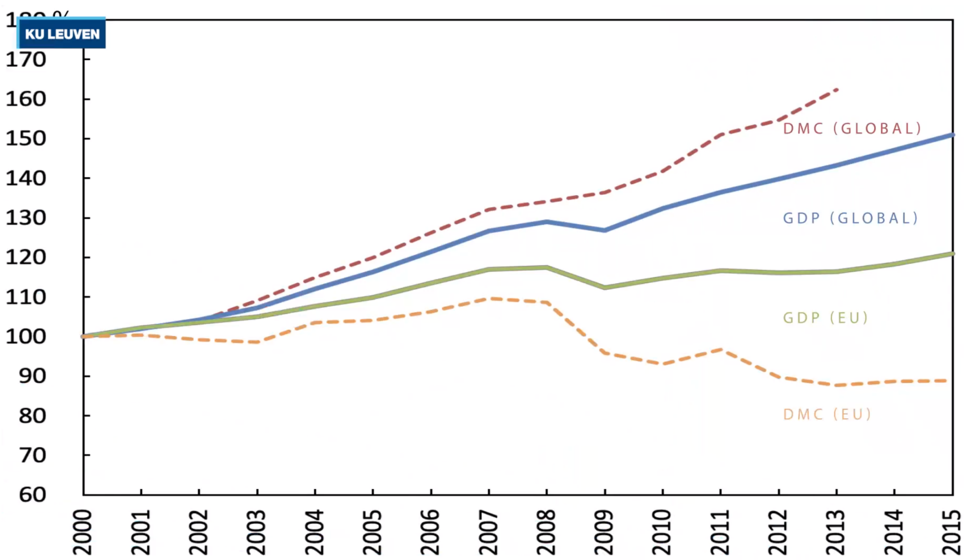


Figure 24: economic growth (GDP) and direct material consumption (DMC)

5.12 Circular economy

A commonly accepted definition of circular economy says that it is an economy in which the value of materials in the economy is maximised and preserved for as long as possible. This means that the input of new materials and their consumption are minimised, that waste generation is minimised and negative and that environmental impacts are reduced throughout the life cycle of materials. The focus is thus on **preserving societal value of material goods**.

This can be done by **decreasing the number of needed products** by keeping products longer in use, by increasing the lifetime by easier repairing during its life and by reuse. Or products could be used more intensively, by sharing its idle time with other people or by only borrowing the product when you really need it.

Another way is making the same or similar products with a **smaller amount of materials**. Strategies to do this are **ecodesign** of products and **process intensification** in order to reduce the waste during production. Materials are also saved when **components from a discarded product still are recovered and remanufactured**.

Finally, materials and alloys are made out of raw materials. A last question then is whether we can **reduce the input of new raw materials**, and replace them by **more sustainable, renewable or recycled raw materials**.

Recycling is a cornerstone, but however, **the last option of the circular economy strategies**. In the circular economy it is even better not to have to discard material, or at least postpone that moment of disposal as much as possible. Preserving value is the main goal.

To illustrate the difference between a linear and circular economy, consider the example of a shirt:

Linear Economy (Traditional Approach):

- Purchase a cotton shirt, contributing to environmentally harmful production.
- Discard the shirt when it goes out of fashion.
- Eventually, dispose of the shirt, contributing to waste.

Circular Economy Approach:

- Purchase a shirt made from locally grown hemp, a more sustainable material.
- Borrow shirts for special occasions from a clothing library.
- Repair any defects, extending the shirt's lifespan.
- Sell, exchange, or donate the shirt at a second-hand shop.
- Repurpose the worn-out shirt as a cleaning cloth.
- Salvage buttons for reuse.
- Finally, send the shirt for textile recycling when no longer usable.

5.13 Circular economy strategies

Figure 25 gives a good framework to categorize strategies to reduce the need for resources.

A product has a certain societal function. To reduce the total need for resources, we can try to get more function out of one product (the first column), to use less materials to make the same products (second column) and to decrease the amount of resources needed to make the materials (third column).

For each of these columns, we can then look at strategies that focus on reducing, improving or renewing.

For example, to get more function out of a product, we can share it (which reduces the total amount of products needed for the same amount of function), we can increase the lifetime (improvement of the product) of a product, and/or we can repair the product (renewing the product). All these strategies allow us to get more use out of one product.

Figure 25: Circular strategies to reduce the need for resources

5.14 Reasons why recycling is not enough

There are limitations of relying solely on recycling as a solution to material resource related challenges.

First of all, **dissipation**. Wear and tear makes us spread small amounts of material over large surfaces with as effect that the material as a resource cannot be retrieved in an efficient way. In the best case this means a **loss of sometimes valuable materials**. In the worst **it can imply toxicity problems**.

Secondly the **concentrations of materials in our products are sometimes so low** that separating them is **economically inviable**.

Thirdly **materials evolve every time they are reused** in a next product life: from polymers that degrade, because the polymer chains are getting shorter and shorter every time they are remolten, to metals like aluminum for which the alloying elements can be added, but cannot be removed by remelting.

For all these reasons **waste prevention**, by dematerializing product functionality, by product life cycle extension or by component reuse **are measures that complement systematic recycling**.

6 Food security

6.1 Study guide

Students should understand **important concepts** such as food security, food gap, land gap, yield gap, the difference between synthetic and bio-based fertilizers, the difference between intensive and extensive farming, the difference between classic breeding technologies and genetically modified crops, plant protection products (PPP), integrated pest management (IPM), sustainable diet, protein shift, food waste and generational renewal.

In addition, students should understand the **environmental impact of food production / agriculture** (land use, greenhouse gas emission, nutrient emission by synthetic fertilizers), including differences between animal-based versus plant-based foods.

Finally, students should have insight into **solutions to increase food security** (increase yields, adopt healthy diets, reduce food waste)

6.2 Food security

Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. As we can see, this concept is very diverse. You can be food insecure because you simply can't afford to buy healthy food, but even if you're rich and have a lot of food available you can be food insecure because you eat unhealthy.

If we look at the evolution of famine deaths on figure 26, we can see that the number of famine mortality has decreased, even with the population growth of the last century. The main challenge of fighting hunger is currently situated in Africa. This has several causes such as climate change (resulting in yield losses), civil wars and anarchy. One of the goals of the United Nations is to end hunger, achieve food security and improved nutrition and promote sustainable agriculture by 2030. However, if we look at figure 27, this is not very likely. One out of ten people worldwide are suffering from hunger and nearly one out of three people lack regular access to adequate food. Furthermore, rising food prices are affecting countries worldwide. Global crises like the climate crisis, the COVID-19 or the recent Ukraine crisis aren't really helping either.

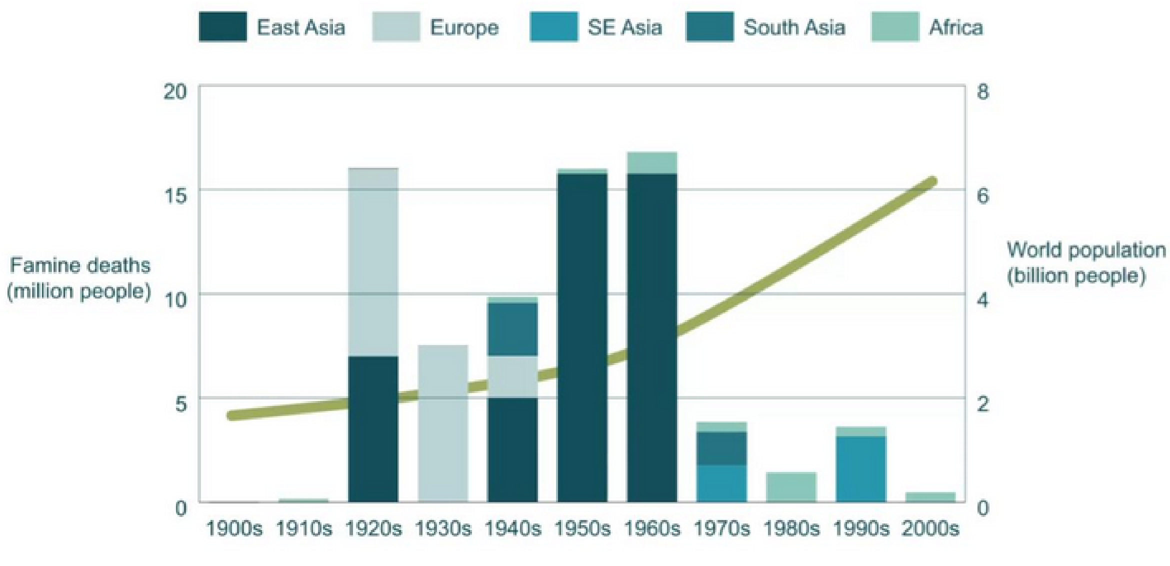


Figure 26: Evolution of famine deaths during 21st century

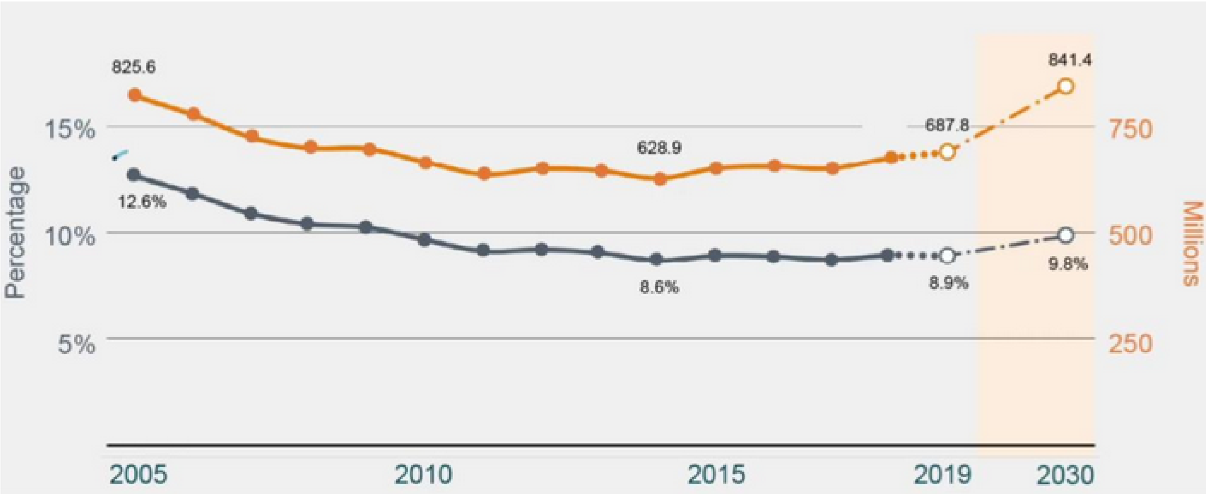


Figure 27: Number of undernourished people (in percentage and in actual numbers)

As already established before, food security goes further then just hunger. We can distinguish between 3 faces of malnutrition when looking at the youngest generation: stunting, wasting and being overweight. **Stunting** means being too short for your age and **wasting** means being too thin for their height. The third face, being **overweight**, is something we see more and more in our own neighbourhoods. The challenge of fighting overconsumption, and hence also overweight and obesity, becomes the longer the more relevant. As a whole, there are more people overweight than underweight and the situation tends to get worse. Unhealthy food is often cheaper and more convenient than healthy food, but overweight leads to food related diseases, including for example obesity, type 2 diabetes, cardiovascular diseases and liver and kidney diseases. Overweight and obesity are measured with the BMI, body mass index. figure 28 also shows there is a clear relationship between caloric intake per person on the one hand and the occurrence of overweight and obesity on the other hand.

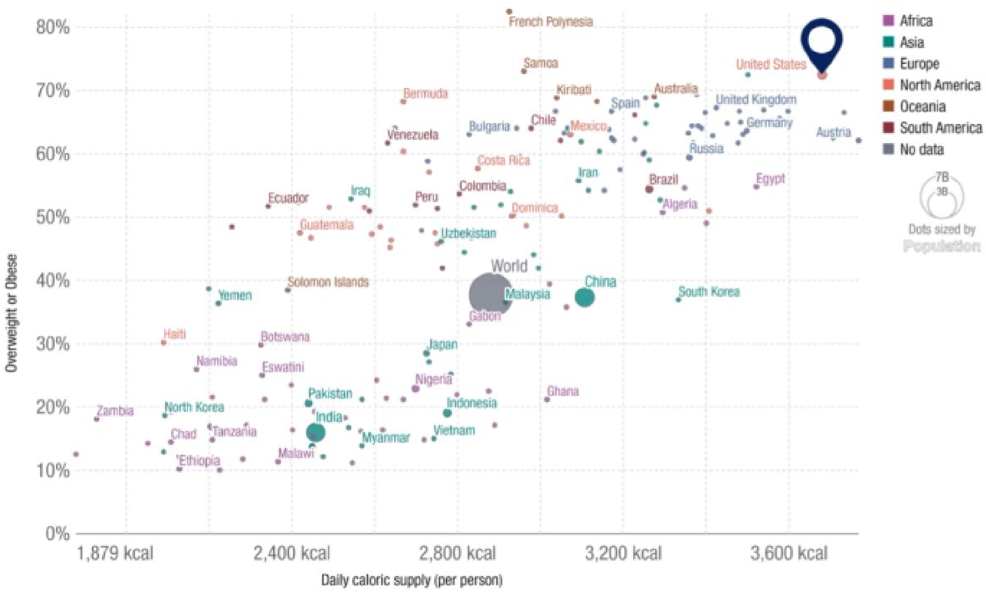


Figure 28: Relation between daily caloric intake and occurrence of overweight

6.3 Main challenges for food security

Two particularly important aspects to discuss whether or not we will we be able to produce enough food to feed the world population are the growing world population and the global surface area that can be allocated for food production.

The **food gap** measures how much food is needed to raise consumption at every income level to meet the minimum nutritional intake target per capita per day. Given the current population growth, we can expect a food gap of 56% by 2050. In other words, where we needed about 13000 trillion calories to feed the world in 2010, we will need to produce over 20000 trillion calories by 2050. This is visualised on figure 29.

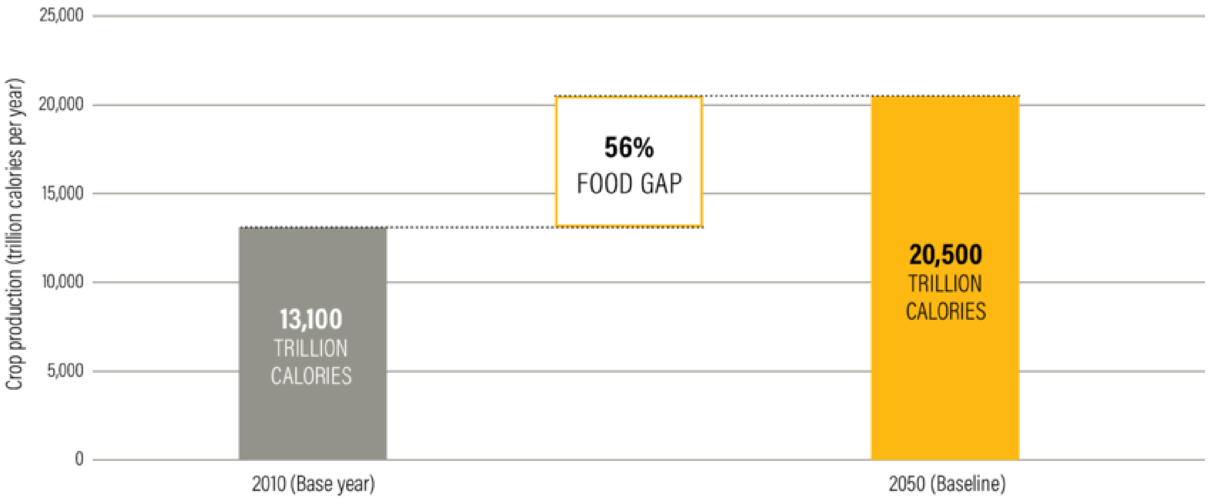


Figure 29: Food gap

This food gap is also reflected in the **land gap**, which is the difference between the projected area of land needed to produce enough food in 2050 and the amount of agricultural land in 2010. On the left of figure 30, we can see that we need approximately 600 million ha of land extra to fill the food gap by 2050. This "business-as-usual scenario" considers the past trends in productivity gains we still have for our crop production system worldwide. However, in a second scenario where no productivity gains are taken into account, we need an extra 3200 million ha of agricultural land, this is more than 3 times the surface of the United States of America or almost all the land that is now covered by forests.

The **yield gap** represents the difference between the potential yield that could be achieved with optimal crop management practices and the actual yield obtained by farmers. This gap highlights the untapped potential for increasing production. Factors contributing to the yield gap include limited access to improved seeds, inadequate use of fertilizers and irrigation, pests and diseases and suboptimal agronomic practices. Addressing the yield gap requires targeted interventions, such as improving agricultural infrastructure, providing farmers with access to modern technologies and knowledge, promoting sustainable farming practices and supporting research and development efforts to develop high-yielding and resilient cereal varieties. By narrowing the yield gap, we can enhance global food security and contribute to the sustainable development of agriculture.

A last big challenge for food security is **climate change**. The results of climate change currently already have an impact on yield and we expect this to continue, mostly in the global south.

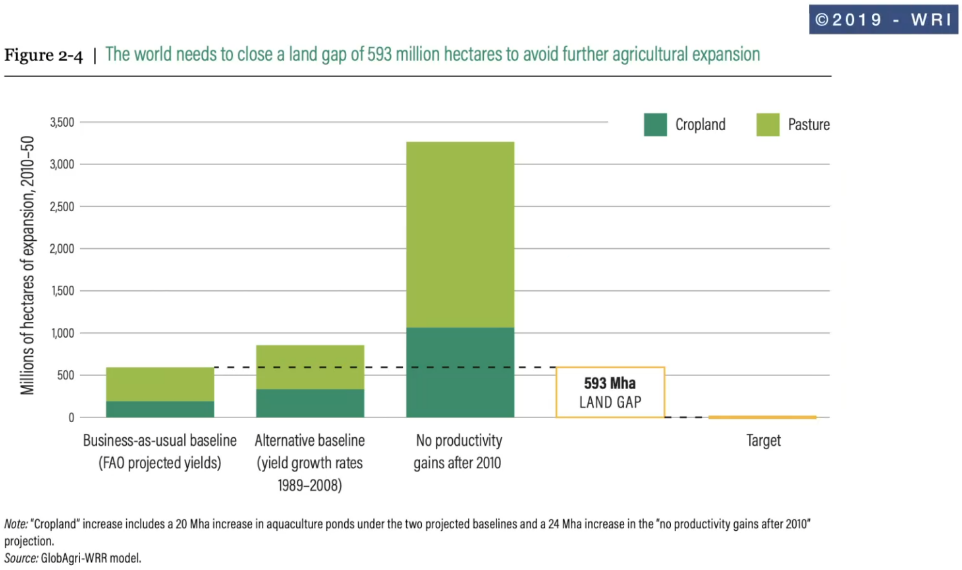


Figure 30: Land gap

6.4 Environmental impact of agriculture

Our food production system has a huge impact on the environment. There are four big environmental aspects that are influenced by agriculture and the food production system, namely land use, fresh water withdrawals, eutrophication and greenhouse gas emissions.

Half of the world's habitable land is used for agriculture. This **land use** has a serious impact on biodiversity. Changes in land use for agriculture and direct exploitation such as fishing, logging and hunting account for 50% of the biodiversity losses.

The second impact is on **freshwater withdrawals**. 70% of global freshwater withdrawals are used for agriculture. When we go more in detail on the water requirement per tonne of food product (figure 31), we can conclude that the water requirement for the production of meat, especially beef, across the full supply chain is much higher than for most fruit, vegetables and arable crops.

The third aspect is **eutrophication**, which is the pollution of waterways with nutrient-rich water. 78% of global ocean and freshwater eutrophication is caused by agriculture. This can be a result of the use of fertilizers such as nitrate and phosphate that can end up in rivers. This will lead to the overgrowth of algae in the water, which will lead to a lack of oxygen in the water, preventing other organisms to live. figure 32 showcases this.

Finally, food production accounts for over a quarter of global **greenhouse gas emissions** and is a result of mainly livestock, crop production and land use. The total emission of greenhouses gasses including carbon dioxide or CO_2, methane or CH_4 and nitrous oxide or N_2O also known as laughing gas, is at the moment approximately 52 gigaton CO_2 equivalents per year. According to a study in 2018, 26% of the greenhouse gas emissions are the result of our food production system. According to a study from 2021 this is even 34%. When we now look a little bit more in detail and do not include land use change, we can see that (the production of methane in the digestive system of) livestock is responsible for approximately 40% of the greenhouse gas emission within agriculture.

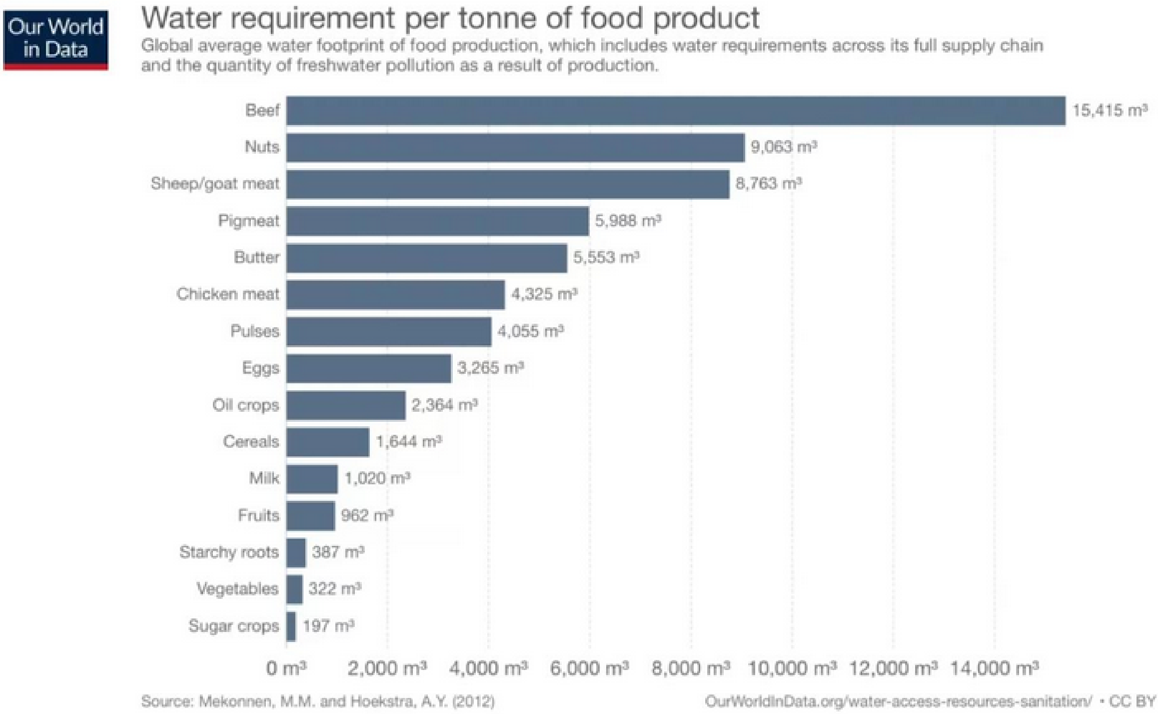


Figure 31: Water requirement per ton of food product

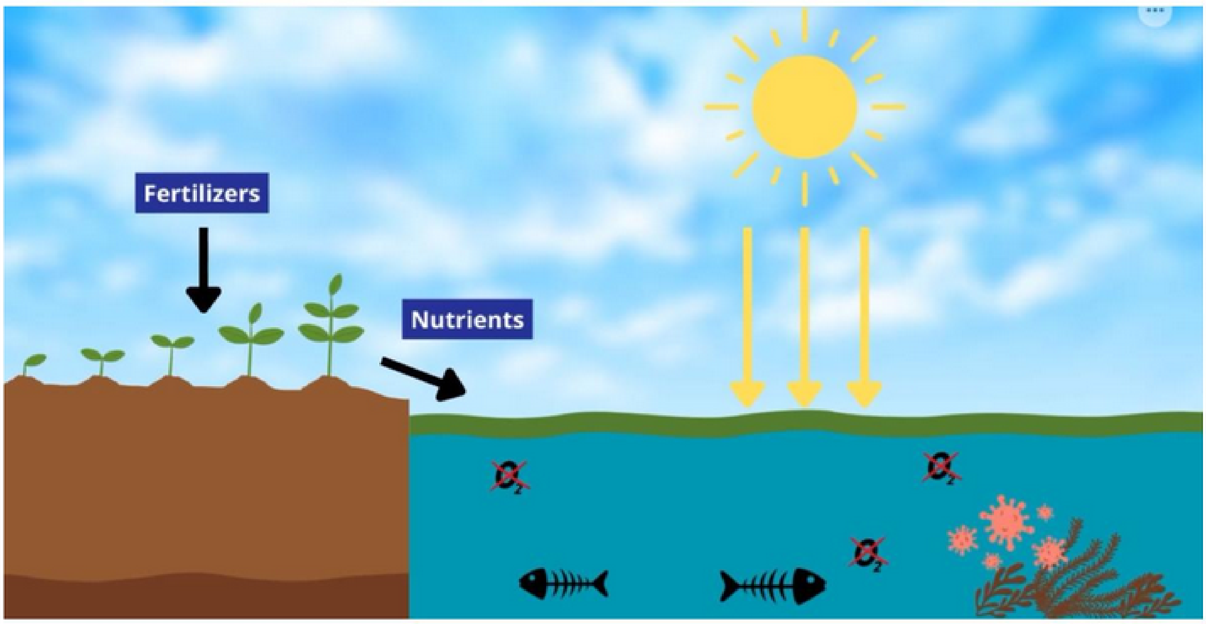


Figure 32: Result of fertilizers

6.5 Sustainable food consumption

Making our food production more sustainable is a pressing global challenge that requires collective efforts and innovative solutions. With a growing population, increasing environmental concerns, and the need to ensure food security, sustainable food production practices are crucial. The most important interventions to reduce the impact of our food production system on the environment and safeguard food security are an increase of the yield, the adoption of healthy diets and a reduction of food waste and losses.

6.5.1 Increasing yield to spare natural habitat

The first intervention is **increasing yield**. Intensification of crop production has been suggested as one of the promising strategies to reduce the amount of land used for agriculture. Interestingly, since 1961 1.75 billion hectares were spared due to crop yield improvements. In a recent study Folberth et al. showed that if we further optimize fertilizer use and distribute 16 major crops more efficiently across global croplands, we can reduce the amount of land needed to maintain current levels of production by nearly 50%.

6.5.2 Key strategies for developing nations

Although a context-specific approach is necessary, there are some key strategies to increase the yield for developing nations. Some strategies, related to the production systems are summarized below:

- **Access to improved inputs** such as high-quality seeds, fertilizers, and efficient low-risk pesticides.
- **Strengthening agricultural extension services** and promoting the transfer of **knowledge and innovative technologies** to farmers. This includes providing training on best farming practices, crop management techniques, and the use of modern tools and machinery.
- Efficient irrigation methods, such as drip irrigation and precision water management, should be promoted to **optimize water use** and minimize wastage.
- Promoting **sustainable soil management** practices, can improve soil health and fertility. This involves practices like crop rotation, organic matter incorporation, and balanced nutrient application, tailored to the specific conditions of each region.
- Encouraging **climate-smart agricultural practices** that promote resilience to climate change is crucial.

6.5.3 Intensive versus extensive farming

Furthermore, we can also make a distinction between intensive and extensive farming. In **intensive farming**, fertilizers, crop protection products and monocultures are used. Intensive farming is also often referred to as conventional farming and leads to high yields but lower biodiversity. In **extensive or organic farming** on the other hand, no synthetic crop protection products, synthetic fertilizers or genetically modified plants can be used. This type of farming results in lower yields but higher biodiversity. Based on a meta study it can be concluded that, depending on the crop as well as the region and environmental conditions, we can have yield reductions in organic farming compared to conventional farming between 19 and 25%. However, when we look at biodiversity, depending on the species groups, we see increases in the number of species between 1 and 38% and an increase in the total number of organisms between 40 and 50% compared to conventional farming. Therefore, we need to make intensive farming more sustainable so that we can produce more on less land, freeing up space for nature.

6.5.4 Sustainable crop breading

The next subject we can study, is **sustainable crop breading**. Classic breeding technologies, such as selective breeding and hybridization, have been employed for centuries to improve crop traits such as yield, disease resistance, and drought tolerance. These traditional breeding methods rely on natural genetic variation within a crop species and involve crossing plants with desired traits to generate offspring with improved characteristics. In recent decades, genetically modified (GM) crops have emerged as a powerful tool in crop breeding. GM crops are engineered to possess specific genes from the same species (different variety; cis-genesis) or other organisms (trans-genesis), offering the potential to introduce desired traits more rapidly and precisely. These traits can include enhanced pest resistance, tolerance to herbicides, and increased nutritional value. Another emerging technology with significant potential is genome editing ("new breeding technology"), which allows for targeted modifications of specific genes within an organism's genome. Techniques such as CRISPR-Cas9 have revolutionized the field of genetic engineering, enabling more precise and efficient genetic modifications in crops.

6.5.5 Plant protection

Global crop production is threatened by various diseases and pests caused by for example fungi, viruses, bacteria and insects. Globally, these diseases and pests still cause up to 20-30% production losses.

Plant protection products or PPPs are used to control these diseases and pests. By definition, these are products that protect plants or plant products during production and storage from pests. Often the terminology "pesticides" is used, but the terminology "PPP" is more correct. The main PPP are insecticides, fungicides and herbicides. They control insects, fungi and weeds, respectively. The use of PPPs can have adverse effects on the environment and humans. For example, certain PPPs can also have an effect on non-target organisms such as pollinators. Moreover, through frequent and improper use resistance to these PPPs can occur.

An impact study performed by the University of Wageningen calculated that yield reductions will occur when we reduce PPPs, especially for crops such as apples, tomatoes, grapes and olives. In addition, we will have to import more crops and there will be declines in net exports, both of which will have significant economic impacts. We therefore will have to be very careful and focus on further sustainably optimizing our crop production systems and engage in agricultural innovations. First, we must strive for a better implementation and follow-up of **integrated pest management (IPM)**. IPM consists of five steps.

Knowledge as a farmer you need to know which pests can harm your crop under which conditions and when.

Prevention of harmful organisms can be achieved by e.g. choosing cultivar that are more resistant to the pest, by implementing crop rotation avoiding build up of your pest inoculum or by hygiene measures e.g. regular cleaning of machinery and equipment.

Monitoring Harmful organisms must be monitored. Adequate tools for monitoring could include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems.

Intervention Based on the results of the monitoring the farmer has to decide whether and when to intervene. Sustainable biological and mechanical methods must be preferred to chemical PPPs but only if they provide satisfactory pest control.

Evaluation and planning The farmer should evaluate the problems he encountered and the interventions he performed in order to optimize the plan for the next season.

6.5.6 Sustainable food consumption

A more sustainable food system has many aspects, including sustainable consumption. It is important to note that sustainable food, as such, doesn't exist. To evaluate someone's consumption behaviour, you need to look at their entire food diet, not just at a single product. Evaluating the sustainability of your diet, one can identify three aspects: health, ecology and social aspects related to food production.

Let's start with the **health** component. At the global level, almost 10% of the adult population is underweight and over 30% is overweight or obese. While underweight is especially an issue in the global South, overweight occurs in the North as well as in the South. This often goes paired with diseases like diabetes type 2 for example. This clearly demonstrates that we need to invest in promoting healthy diets if we want to strive for sustainable food consumption.

The second component of sustainable food consumption is **environment**. The number of labels claiming environmental friendly food is endless. But if we look at the data on GHG emissions of our food system in figure 33, it becomes clear that it is most relevant to focus on what is on your plate, rather than to focus on how your food is produced, where it comes from, how it is processed or packed because the majority of the footprint of food relates to land-use and agriculture.

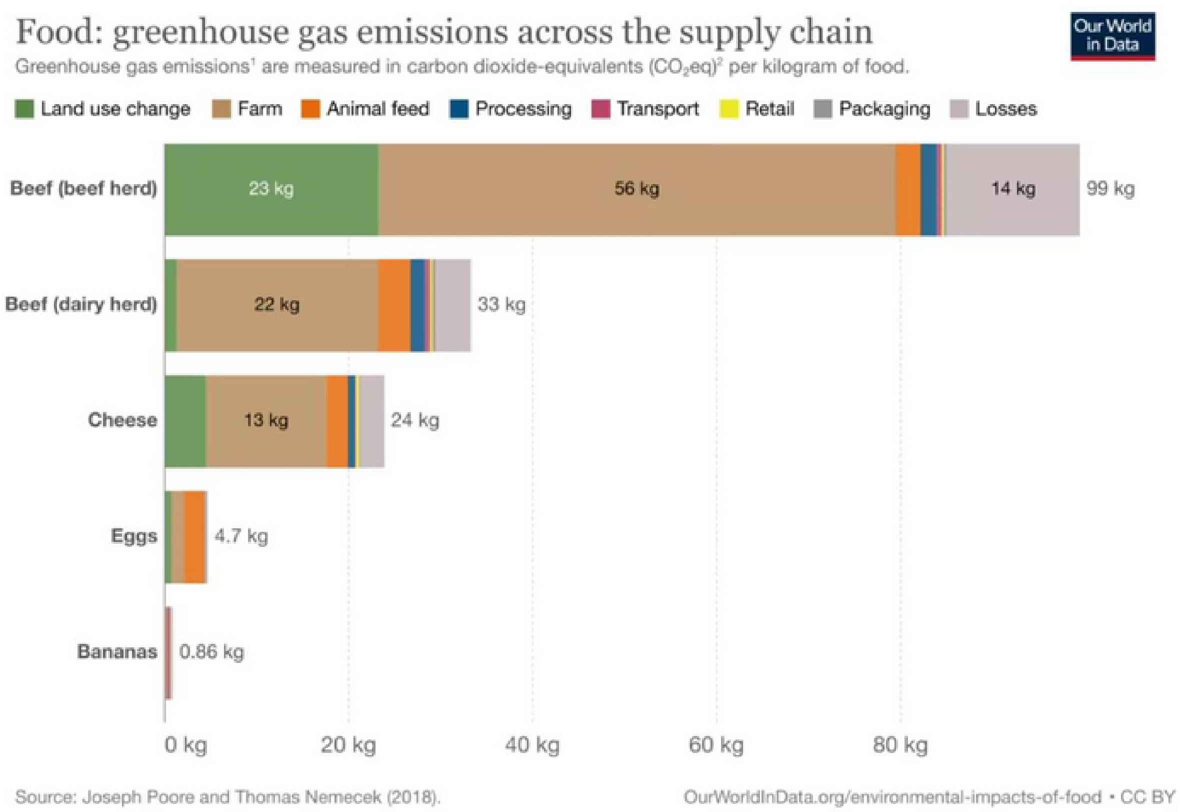


Figure 33: Greenhouse gas emissions of food across the supply chain

Overall, a better balance between animal and plant based products in our diets, contribute significantly to lowering our footprint. A **protein shift**, where you move from a meat based diet to a plant based diet, is not just more healthy, it is also better for the environment.

The third aspect of sustainable food consumption has to do with **social and economic aspects**. The power in the food system is very badly balanced, with farmers being the weakest actor in the food chain. Fair trade labels have been introduced as a tool to develop more 'fair' food systems.

6.5.7 Food waste

Food waste is defined as food and the associated inedible parts removed from the human food supply chain in the sectors of retail, food service and households. In this definition, "removed from the human food supply chain" means one of the following end destinations: landfill, controlled combustion, sewer, litter/discards/refuse, co/anaerobic digestion, compost/aerobic digestion or land application. Food itself is defined as any substance – whether processed, semi-processed or raw – that is intended for human consumption. Therefore, food waste includes both **edible parts** (i.e., the parts of food that were intended for human consumption) and **inedible parts** (components associated with a food that are not intended to be consumed by humans).

Food waste reduction offers multi-faceted wins for people and planet, improving food security, addressing climate change, saving money and reducing pressures on land, water, biodiversity and waste management systems.

8 Buildings

8.1 Study guide

Module 8 on Buildings sketches basic insights into the environmental impact of buildings and their role in a transition towards a more sustainable society.

- You should clearly understand the concepts discussed in the module, be able to recognize examples, and be able to read the diagrams.
- Important concepts: role of buildings in reducing the environmental impact, existing policy on energy performance of buildings, life cycle of a building, life cycle assessment, operational and embodied carbon, carbon footprint and ecological footprint, life cycle financial impact of buildings, possible solutions for building renovation, possible solutions to reduce the environmental impact of buildings, urbanization and urban heat island.
- It is not necessary to memorize the numerical values shown in the diagrams, but it is necessary to understand the meaning of the diagrams.

8.2 Environmental impact of construction

8.2.1 Context

The building sector is responsible for 40% of the energy use and 36% of greenhouse gas emissions. The building sector hence plays an important role in climate change. Besides the global impact of these greenhouse gas emissions, these cause local effects as well. In cities, temperatures are rising and are typically higher than in suburban areas. This is called the **heat-island effect** and is caused by higher absorption of solar radiation by buildings and infrastructure. This can be avoided by integrating water and vegetation. To date 55% of the global population lives in cities and it is expected that this will increase to about 70% by 2050, this is called **urbanization**.

To reduce the **impact of buildings on climate change**, important steps have been taken. In 2010, the **European Commission introduced a directive on the energy performance of buildings** that requires that all **new buildings have to be nearly-zero energy**. This resulted in a transition of buildings, where the buildings today are well insulated, air-tight, ventilated and are foreseen of at least a share of renewable energy to fulfil the nearly-zero-energy requirements.

8.2.2 Main challenges

To reduce this environmental impact, we are facing **various challenges**. A first important challenge is **reducing the energy use of existing buildings**. These buildings are not well insulated and require an in-depth renovation. To reach the European climate goals, the renovations should be **deep energetic renovations**. This means that replacing windows or adding roof insulation is insufficient. By re-using the demolished parts of the buildings, we can reduce the need for virgin resources. **Buildings should hence be seen as material banks**, enabling urban mining.

A second challenge relates to the need to **reduce embodied impacts**. These are **the greenhouse gas emissions due to the production, transport and end-of-life treatment of materials**. So far, the main efforts to reduce the climate change impact of buildings focused on reducing the operational energy use of buildings. To further reduce the carbon footprint of buildings, it is hence **important to not solely focus on the operational phase** (blue blocks on figure 34), **but also take into account the embodied impact** (red blocks on figure 34).
If not, this could lead to a burden shifting from the operational to embodied carbon, potentially resulting in higher life cycle emissions. For newly built nearly-zero energy buildings, the **embodied emissions have become evenly important as the operational emissions**. This is visualized by the dashed line on figure 34. The majority of the embodied emissions occur at the moment of renovation or construction, these are called **'up-front' emissions**. Reducing the upfront emissions is more urgent.

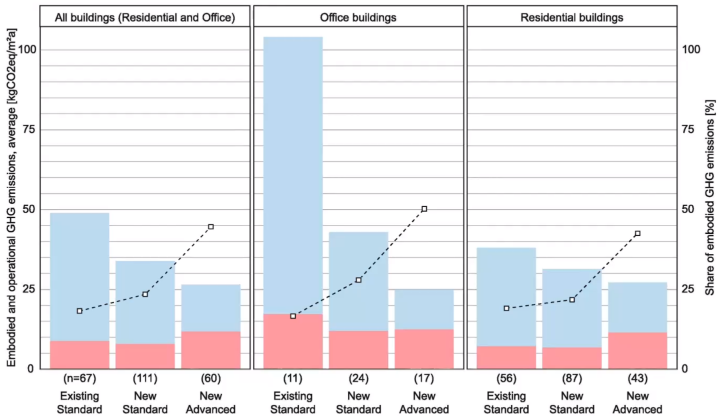


Figure 34: Global trends in embodied and operational life cycle emissions

Another challenge relates to other **environmental pressures caused by the building sector, beyond climate change effects**. Resource extraction for construction materials, land use for buildings, fresh water use, fine dust emissions, plastic waste, are causing important pressure on our planet in terms of for example biodiversity loss, respiratory effects, shortages in fresh water, and acidification of the ocean.
For many of these resources, we are currently beyond the planetary boundaries. Or, in short, **our ecological footprint is beyond the Earth's carrying capacity**. There is hence an urgent need to further rethink the building sector to reduce our ecological footprint.

8.2.3 Life Cycle Analysis

There is no simple and straightforward solution available to solve the various challenges the construction sector is facing to reduce its environmental impact. A combination of steps and strategies will be required to enable a further transition of our buildings and cities.
To avoid burden shifting in time and impacts, it is important to have insights into the consequences of measures from a life cycle perspective. This means that all **life cycle stages of buildings** are considered when assessing their environmental impact, from the **production and construction phase**, over the **use phase** till the **end-of-life phase**. For buildings, the use phase will remain a very important one, seen the relatively long service life of buildings.

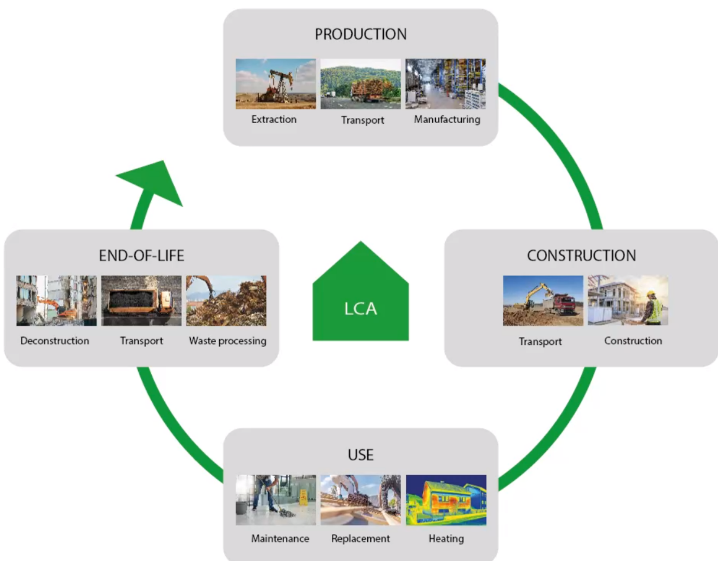


Figure 35: Life Cycle Analycis (LCA) of buildings

In **Life cycle assessment**, typically three areas of protection are assessed: the impact on depletion of resources, the impact on quality of ecosystems and the impact on human health. The results of an LCA hence are not limited to the carbon footprint of a building, but consists of the environmental footprint. This environmental footprint covers a whole range of relevant environmental effects, such as climate change, ecotoxicity, resource depletion, carcinogenic effects, etc.

8.3 Residential stock

Figure 36 shows three types of residential buildings. For each, the life cycle environmental impact of four variants is shown. The first bar represents the impact of the original dwelling, without any renovation measure. The second is the same building but built according to the energy performance standard of 2010 and the final two variants represent buildings that are even better insulated and for which other materials were chosen.

The analysis shows that the **main driver of the environmental impact** of the **oldest buildings** in our stock is the **energy use** for heating.
The life cycle impact of the **newly built variant** shows a much lower life cycle environmental impact due to an **important reduction of the operational energy use**. The **upfront impact** has only **slightly increased**. This increase is hence largely compensated for by the reduced operational impact.

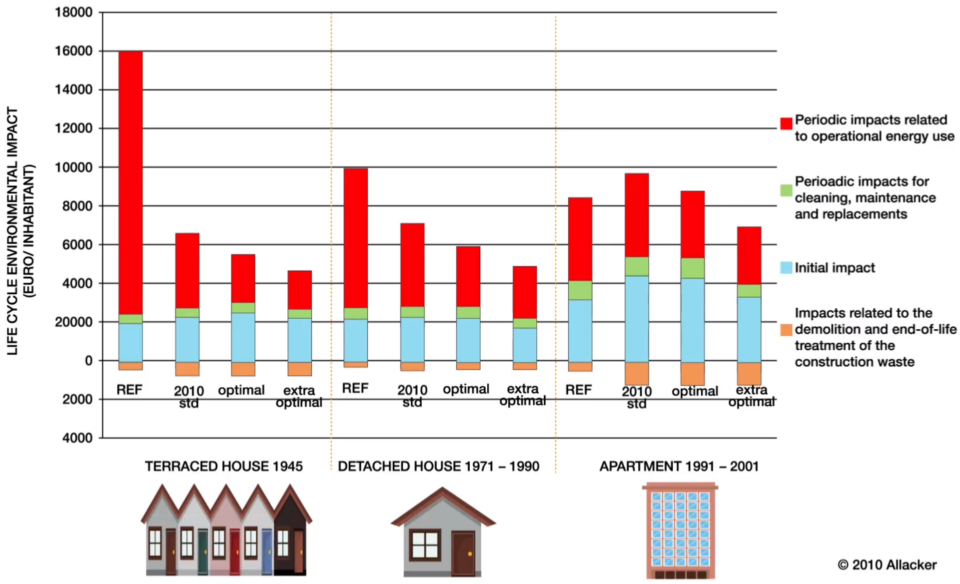


Figure 36: Life cycle environmental impact of different types of buildings

Embodied (upfront) impacts can be reduced by using less materials, choosing for materials with a lower environmental impact (cleaner production), circular building (e.g. urban mining) and extending the service life of buildings.

Comparing the various building types reveals that the building type and layout influence the life cycle impact of the building, even if the insulation level and airtightness are identical.

Besides the environmental life cycle impact, **also costs are important to ensure affordability**. The same analysis but from an **economic perspective shows significant differences**. Now, **operational energy use** is **not the main driver anymore**. The **main driver** for the costs is **the investment cost and the maintenance cost** due to high labour costs. This can be seen in figure 37.

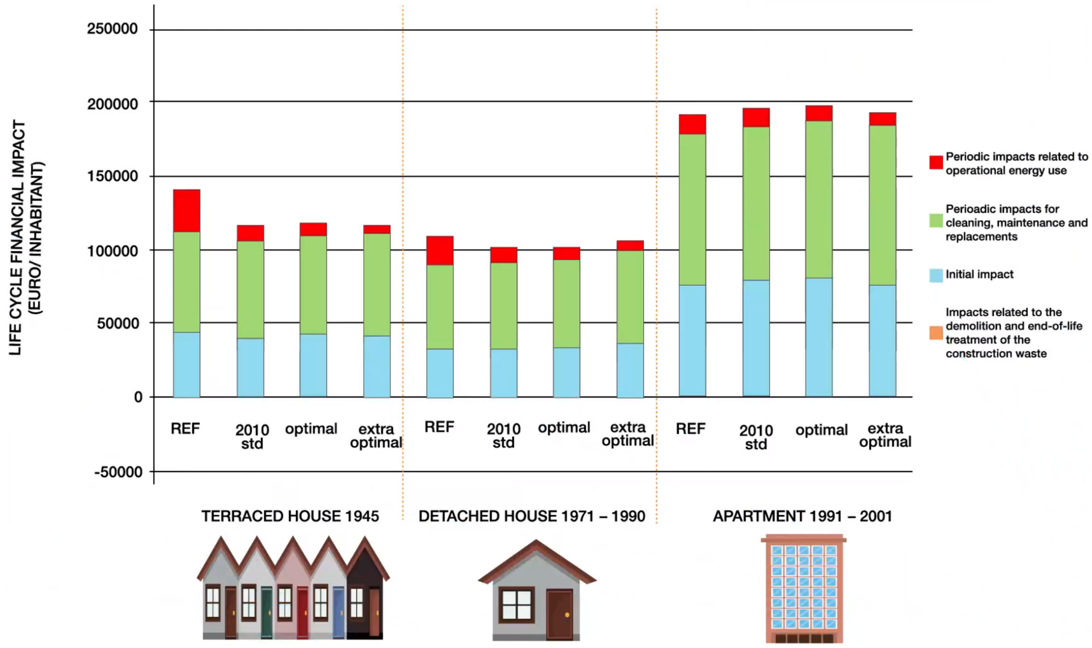


Figure 37: Life cycle financial impact of different types of buildings

When looking at a **higher scale level** instead of the building level, the scope is broader. It includes the impact of the land used by the building itself and used by the infrastructure required to access the building. In addition, the mobility of the residents is now included. The materials needed for roads, service systems and parking lots are also included.

Comparing two different locations, city centre versus suburban area, shows that the mobility impact is (on average) much lower for people living in cities due to a lower use of car-transport. Especially for the nearly-zero energy building, the mobility is the main driver of the life cycle impacts. It can be concluded that **the location of buildings**, and hence urban planning, is **crucial when aiming for a reduction in the environmental impact** of the built environment.

8.4 Sustainable construction

Thanks to the **EU policy, operational energy use of new buildings is well managed** and all stakeholders in the construction sector (architects and engineers, material producers, constructors) have enabled an important transition in the sector. The energy performance of newly built dwellings to date is much better than buildings that were built 15 years ago. The following **main challenges have been identified to further lower the environmental impact of new buildings**:

- First, **reducing the impact of the materials** by A) well-thought design of buildings to reduce the material need, B) producing and using materials with a lower environmental impact and C) circular building (high-value reuse and recycling of materials).
- Second, **reducing the impact of transport by sound urban planning**.
- Third, **reducing the land used by buildings** due to densification. This will lower the environmental footprint of buildings directly, and indirectly lower impacts due to increased public transport as public transport becomes affordable with higher densities.

9 Mobility

9.1 Study guide

This Chapter on mobility will be on the impact of person and freight transport and sustainable transport solutions. Make sure you:

- Understand the different strategies mentioned in this module (e.g. Mobility as a Service, Consolidation of freight transport,...)
- Understand the 4S framework and classify strategies for person and freight mobility according to this framework
- Understand the role price incentives (money) and technology can play to make our mobility pattern more sustainable
- Understand the links with the other modules

9.2 Strategies

A first strategy to reduce the impact of our mobility systems, is a modal shift related to **cycling**. The more people we get on a bike, the better. An increased attention for the safety aspects and appropriate infrastructure is needed to encourage people to use a bike. More and more cities also implement a circulation plan. Such a plan explicitly steers the different traffic flows in and around a city, with one way streets and dead-end streets. It typically moves longer distance traffic around the city and limits the options for people with a destination inside the city.

Another important modal shift, is related to **public transport**. We want less cars on the road and more people using trains or buses. To have lower emissions per passenger-kilometer, we typically need around 10 people on a bus. To make public transport an attractive option, a good service is essential: comfortable, punctual and with a high frequency. Furthermore, the travel time using public transport should not be more than one-and-a-half time the travel time by car. That is why buses should not stop too often and can strongly benefit from separate bus lanes. But you also need to bring together the different flows and the different types of public transport in a network with a clear hierarchy. The large flows are served by a core network, with a high frequency, a high throughput and a high speed. For the smaller flows the service should be more flexible and "on-demand" to be effective and efficient. These on-demand services should bring people to the core network as efficient as possible.

Parcel delivery and small freight vans are a large part of our current mobility challenges, and are expected to increase. A change in modal split can be initialized by local authorities: imposing limitations for trucks, limit the size of trucks that are allowed, using limited time windows in certain streets. Another option is called "consolidation". The idea is that all parcels and freight are brought to the border of a city, for instance to a city hub. There, all these products are collected and then redistributed over smaller electric vehicles to be distributed in the city center in the most efficient way.

The **15-minute city concept** is an urban planning concept in which most daily activities and necessities (work, school, groceries, doctor, ...) can be easily reached by a 15-minute walk or bike ride.

Mobility as a Service combines different types of transport to ensure the wanted mobility. In this concept you are no longer the owner of your mode of transportation. This makes it easy and cheaper for the user to use more sustainable types of transport.

To address the challenges related to mobility, we will have to increase the price of mobility, so that it resembles the actual costs. A first step in increasing the price, is by reducing systems that make transport cheaper, such as subsidized cars or free parcel delivery. Apart from reducing cheap transport, the price of transport should in some cases be increased to match the actual cost. In general, also for other challenges related to mobility, this can for instance be done by appropriate **CO2 pricing**.

When the price of transport reflects the actual cost we will see four long term effects:

- People will live closer to their work.
- People will live closer together.
- People will work more from home.
- Parcel delivery and freight delivery will be bundled more.

Specifically for mobility, a crucial part of the solution lies in **road pricing**. It means that car drivers have to pay a certain price based on when and where they are driving. Road pricing can and should steer mobility: encourage car drivers to different times to avoid congestion, make alternatives more attractive, support carpooling, make smaller and greener cars more attractive,. . .

It should also be noted that different types of road pricing are possible and it will depend on the specific situation which type is preferred:

- **Cordon tolling**: where people have to pay when entering a certain area, such as a city, such as in Londen or Stockholm.
- **Gps- and carbased**: where people pay based on when and where they are driving.
- **Road based**: where you pay to use certain roads, like the "péage" in France.

9.3 The 4S-framework

Today the demand for mobility of people and freight keeps growing. At the same time the available space is limited in and around most cities in the world. This combination leads to increasing congestion, loss of time and emissions. To deal with this challenge, there won't be a simple and straightforward solution, but we will require a combination of different steps. These steps can be divided in 4 categories: the **4S-framework**.

The first category is **'Suppress'**, this is about not having to make certain movement. A typical example here is working from home or having more online meetings.

The second category is **'Shorten'** or decrease the distance that you need to travel. For instance working closer to home or living closer to basic facilities like schools and shops.

The third category is **'Shift mode'**. A modal shift from car to bike or from truck to train. By using a different mode, we can often reduce traffic and/or environmental cost. For example, let's take a look at the external environmental costs for freight transportation in Figure 38, calculated per 100 ton-kilometers. This graph sums up the costs of heavy metals, CO2, NOx, etc. Here we see a clear difference between for example trucks compared to trains.

The fourth category is **'Smart technology'**. By improving the technology used in our vehicles, we can also reduce environmental cost. If we look at the same graph of Figure 38, we not only see a difference between the modes of transport, but we also see that the environmental cost has decreased between 2000 and 2014. This is due to technological improvements.

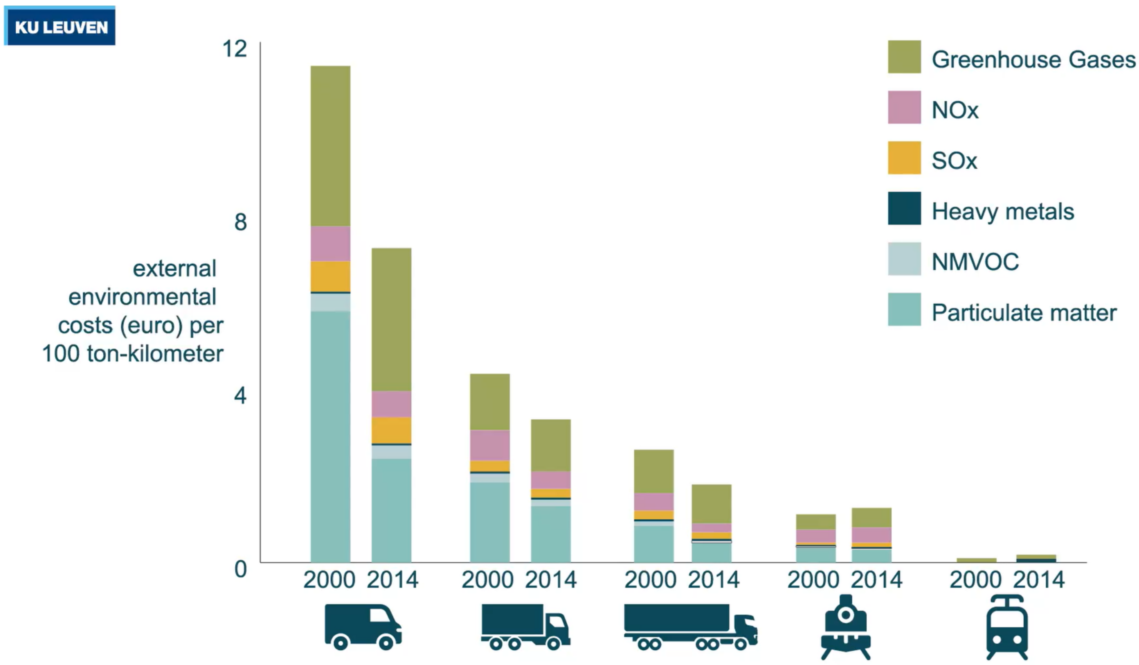


Figure 38: External environmental costs per 100 ton-kilometers, 2000 versus 2024

9.4 The role of price incentives and technology

When looking at the **financial aspect**, mobility is too often too cheap. The price of mobility should be increased, so mobility is considered more when decisions are taken. A first step in increasing the price, is by reducing systems that make transport cheaper, such as subsidized cars or free parcel delivery. There also needs to be an appropriate CO_2 pricing to discourage people from buying big cars that are often paired with increased emissions, an increase in fatal accidents with cyclists and pedestrians and other costs related to transport.

When the price of transport reflects the actual cost we will see four long term effects: People will live closer to their work. People will live closer together. People will work more from home. Parcel delivery and freight delivery will be bundled more. This solution is represented by the 4S-framework we discussed earlier.

Other **structural solutions** are related to infrastructure. **Low emission zones** clearly have a positive impact on emissions. They lead to greener cars and better air quality. **Circulation plans** with a clear choice for public transport, cycling and pedestrians also have a positive impact.

Some people are convinced that **technological development** will solve all our problems, also all our mobility problems. An argument that is often cited is the use of **autonomous vehicles**. Clearly autonomous vehicles could have a large impact on both individual and public transport. It would probably be safer and cause less accidents. If some social hurdles were mitigated, it might also increase car - and ride sharing. It would seem that there are no downsides to autonomous vehicles. However, there is one problem: the switch to autonomous vehicles would be too late to prevent climate change. So, we need to find other solutions.

One possible solution is **car sharing or other Uber-like systems**. This sounds good in theory because it decreased the number of vehicles and vehicle kilometers. But in practice, it is currently just a cheap taxi-service, by poorly protected drivers, replacing movements by public transport or on foot. So, from a societal perspective many questions could and should be raised.

Another possible solution in **hyperloop**. The basic idea is that you build tunnels underground or closed pipes above ground, and by making these almost vacuum, capsules or pods can travel through these pipes at enormous speeds, up to 1000km per hour. The believers promote the hyperloop for passengers by mentioning that it would not take up any space. However, this 'solution' brings problems related to its capacity. If you assume about 28 passengers per capsule, and a maximum frequency of 12 capsules per hour, giving you 5 minutes to put the capsule in the pipe, close the airlock and get it vacuum, then you get 336 passengers per hour per tube per direction. This is a lot less than the capacity of trains and planes that already exist.

To conclude, technological developments can play a part in solving the challenges related to mobility, but they should be properly managed and accompanied by more impactful measures, such as increasing the price of mobility.

9.5 Link with other modules

We can find multiple links with mobility and the other modules of this course. For instance, the is a link with **climate and biodiversity**. Transport accounts for around one-fifth of global CO2 emissions. About 75% of these emissions comes from road vehicles for both passenger as freight transport. Apart from carbon, cars also emit NOx, SOx and particulate matter, leading not only to climate change but also to air pollution.

Another link that can be found is the one with **raw materials**. When addressing mobility related challenges, much is expected from the shift from current vehicles with combustion engines towards electric vehicles. It should be noted, however, that these electric vehicle also required the usage of raw materials, which are not always easily, and sustainably, available.

A third link we can find is a link with **economy and governance**. A worldwide or European CO2-tax would have a huge positive impact on climate change, certainly also related to mobility issues. A more detailed explanation on carbon taxing can be found in the module on Economy of sustainable development.

There also is a link with **energy**. Even after switching completely to electric vehicles instead of combustion engines, we still do not have a sustainable mobility system. Even then, for example, scarce raw materials and sustainable electricity generation are required.

Last but not least, there also is a link between mobility and **inequality**. As mentioned in the module on inequality, many "sustainable" measures or solutions for the challenges require adjustments and special care to make them socially acceptable.

10 Economics for sustainability

10.1 Study guide

This chapter will be on the connection between economy and environment and the shortcomings and opportunities of economics for sustainable development. The study guide for this chapter of the MOOC was a complete mess and basically covered the whole transcript. That is why, even though this part of the summary is still based on the study guide, there won't be a structured overview of it.

Typical questions for this chapter are:

- Definitions, terminology: be able to explain the definition, give examples
- Graphs: be able to explain and interpret the graphs
- Principles: be able to explain, give examples

10.2 Gross Domestic Product

The **Gross Domestic Product** or **GDP** is a measure of total production that is used to reflect the economic health of a country or region and has strongly increased since the end of the 19th century. Figure 39 shows this exponential growth.

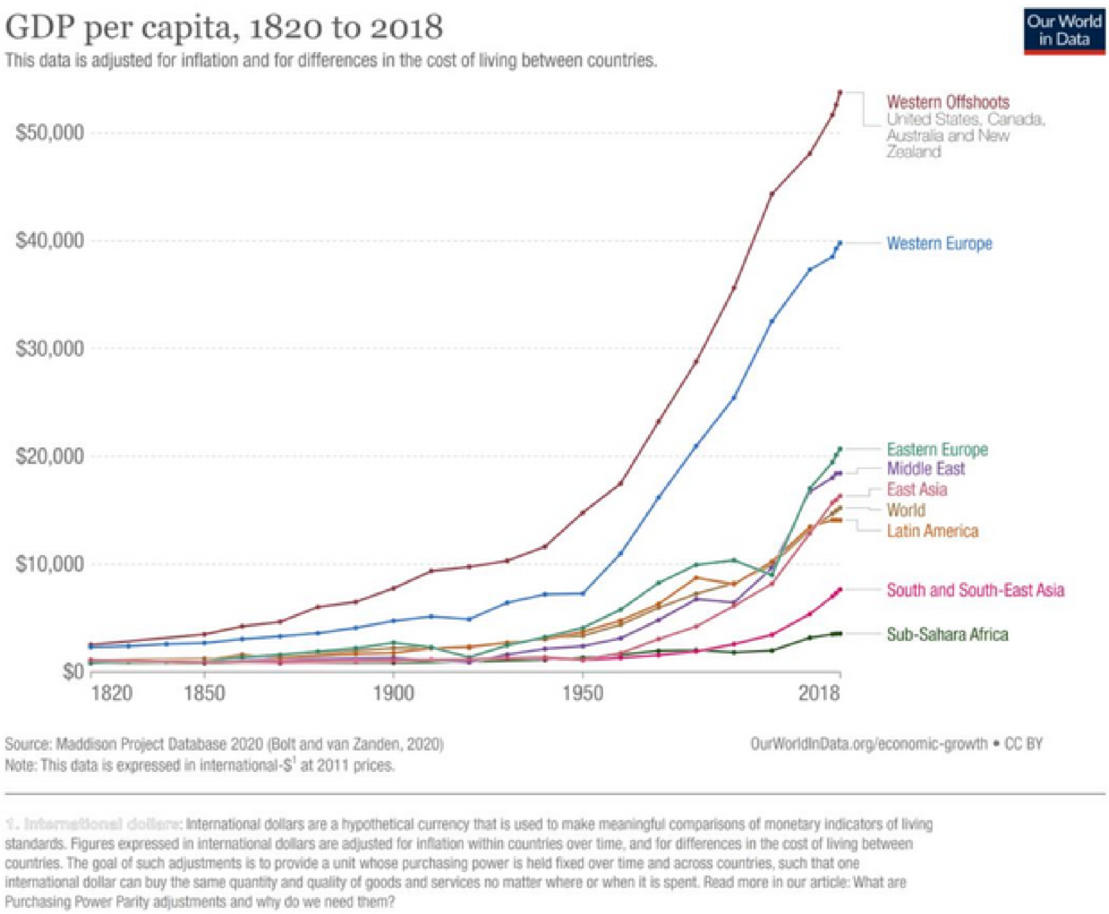


Figure 39: Increase in GDP since 19th century

This increase in GDP went together with a lot of other positive phenomena, such as an increase in life expectancy, an increase in literacy, a decrease in hunger, and so on. However, at the same time, we also saw a rise in environmental pressures, such as greenhouse gas emissions, global warming, plastic pollution, declining biodiversity, and many more.

Economic growth is the annual percentage change of real GDP. Real GDP means it's GDP measured in monetary terms, but it's corrected for inflation and price changes.

There are multiple ways to define GDP. The first approach is the so-called **added value approach**. We define GDP as the value of all final goods and services that are produced in a given country in a given period of time. A second way to define GDP is to look at incomes. All that value added in the GDP is giving rise to incomes, incomes to the persons who own the factors of production. Factors of production are labour, capital and land. So in the second approach to GDP, the **income approach**, GDP can be defined as the sum of all the incomes that are earned by the owners of factors of production in a given year, in a given country.

We should look at GDP as **a measure of production and of economic activity**. It was not intended to be a measure of prosperity or well-being or happiness. So **a lot of things are not picked up by the concept of GDP**. A first example of something that is missing in the GDP is a good idea about the distribution or the inequality. A second thing which is missing from the GDP is unpaid work. A third element that is not included in the GDP are changes in the quality of the environment.

Figure 40 shows the emissions and GDP per capita for the different countries. Looking at the graph, we can see there seems to be an increasing relationship between GDP per capita and emissions per capita. Richer countries, with a higher GDP per capita, have higher emissions per capita. We can also see that the big countries, like China and India, are on an intermediate level of emissions. If we study the evolution of the emissions versus the GDP per capita during the 20th and 21st century, like depicted on Figure 41, we notice two different trends. Countries like China and India started at a low level of both emissions and GDP per capita, but they gradually increased over time and are still increasing. On the other hand, we have countries like Belgium and the United States that started increasing at an intermediate level of emissions per capita, but then reached a peak and started decreasing. This pattern is observed for many developed economies and the idea behind it is the so-called Kuznets curve

10.3 The Kuznets curve

Like we mentioned in section 10.2, the **Kuznets curve** is used to describe the pattern we see in the evolution of emissions and GDP per capita for countries with developed economies. The Kuznets curve is typically an inverted U-shape of form (Figure 41), meaning that initially countries have very low emissions per capita and GDP per capita. But then they start to economically develop, and they start to industrialize. During that industrialization phase, we see rapidly increasing emissions in per capita terms, but also rapidly increasing GDP per capita. At a certain time, there typically comes a moment when economies start to shift away from this heavy industry towards other activities, like, for instance, services. This means that the emission intensity of that economy is gradually decreasing and the growth of their emissions is also decreasing. This can also be influenced by governments that are stepping in and are developing environmental policies to combat pollution. This evolution of first **increasing, peaking and then decreasing emissions**, that is what we call the Kuznets curve.

However, it is important to note that this curve is a correlation, and not a causal relationship. Hence, we can't just simply say that the low-income countries just need to focus on growth in order to solve the solution problems.

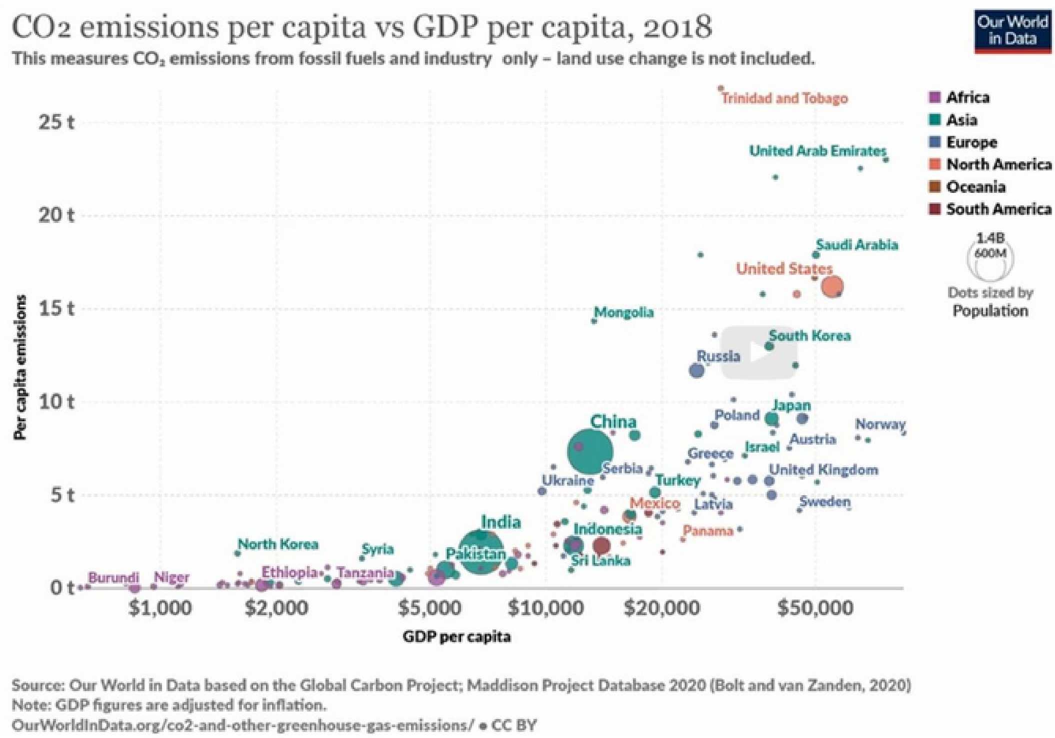


Figure 40: CO_2 emissions per capita versus GDP per capita, 2018

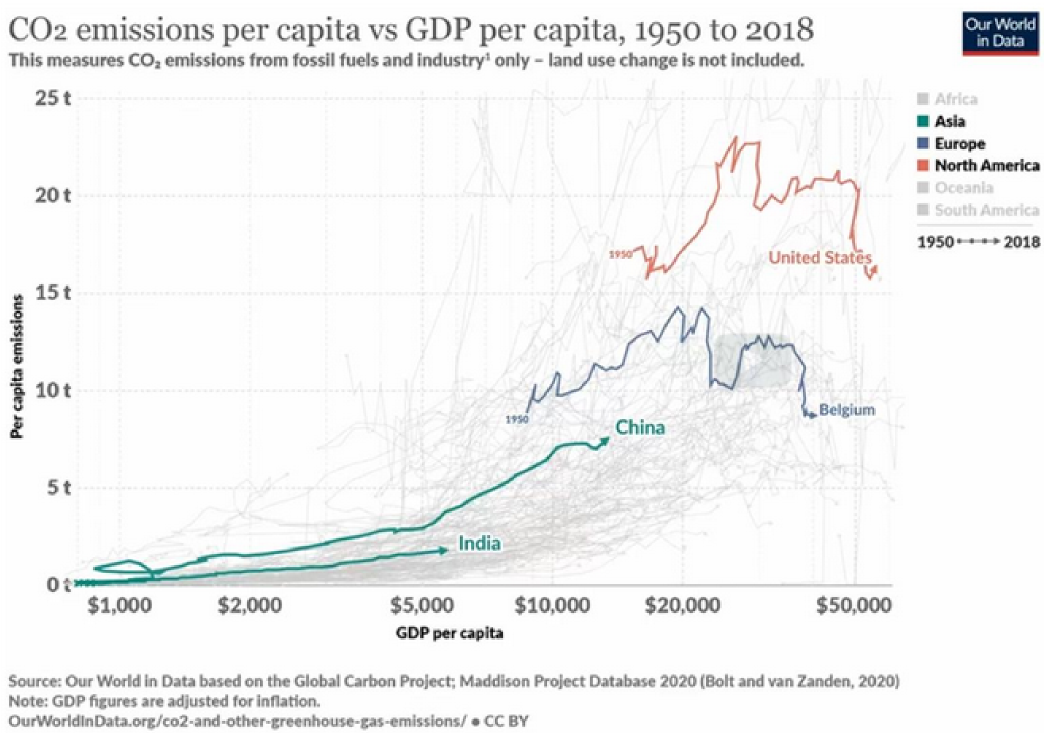


Figure 41: CO_2 emissions per capita versus GDP per capita, 1950 to 2018

10.4 Production versus consumption based emissions

We can make a distinction between production and consumption based emissions. Up until this moment, we have been looking at emissions in the production perspective. **Production perspective emissions** are a measure of emissions within a given territory of a particular country. However, this is not the full story because we are not only consuming goods that are produced in our country but are also consuming goods imported from other economies. The emissions of these imported goods are not considered in the production perspective we have used so far. If we want to get a fairer approach of our emissions, we should also consider this. This is done by the **consumption perspective**.

If we look at our country, we can see that the consumption based emissions are very high. The production based emissions of Belgium are intermediate. For other (production-based) countries like China, we see the opposite. If we calculate the absolute level of emissions, we get an overview of the actual emissions we are causing. We can call this our **carbon footprint**.

10.5 Drivers of environmental impact

If we want to take a look at the drivers for CO_2 emissions, we first start with the **IPAT relationship**. This relationship says that environmental impact (I) is the product of 3 drivers: population (P), affluence or GDP per capita (A) and technology (T). The product of these 3 drivers gives rise to the environmental impacts. A special case of this IPAT relationship is the **Kaya decomposition** of greenhouse gas emission evolution. This decomposition makes a more sophisticated distinction between two technological drivers. Hence, it states the CO_2 emissions can be written as a product of 4 factors.

Like previously mentioned, the first driver is **population**. The more people there are, the more goods and services are produced and the more CO_2 will be produced.

The second driver is GDP per capita. This is a measure of **affluence**. When people get richer, they typically demand more goods and services which will also result in a rise of emissions.

In terms of **technology**, the Kaya decomposition makes a distinction between energy intensity and CO_2 intensity of energy production. The **energy intensity** measures how much energy we need to produce one unit (for example $1) of GDP. Unlike the previous factors, we expect the energy intensity to go down over time because our economy becomes more of a service economy instead of an industrial economy and because of technological progress.

The CO_2 **intensity of energy production** measures how much CO_2 is released by producing one unit of energy. Since we are currently decarbonizing our energy production by investing in solar panels and wind energy, we also expect this to go down over time.

Figure 42 shows the actual global reality of these different factors and their evolution. We can see that the emissions and the GDP grow at the same percentage rate, so there is no decoupling between them. If we look at this evolution for Belgium, we can see that this is not the case. For Belgium, the curves are separating and there is **absolute decoupling**: whereas on the one hand GDP per capita is still growing, we see that emissions are going down in absolute amount. A **relative decoupling** would mean that emissions are growing but at a slower pace than the GDP per capita. When we look at the different Kaya factors, we see the same trend as described before for the global overview, with one difference: our population is growing a lot slower than the global population. This results in slightly decreasing CO_2 emissions since 1990. We can see this in Figure 43.

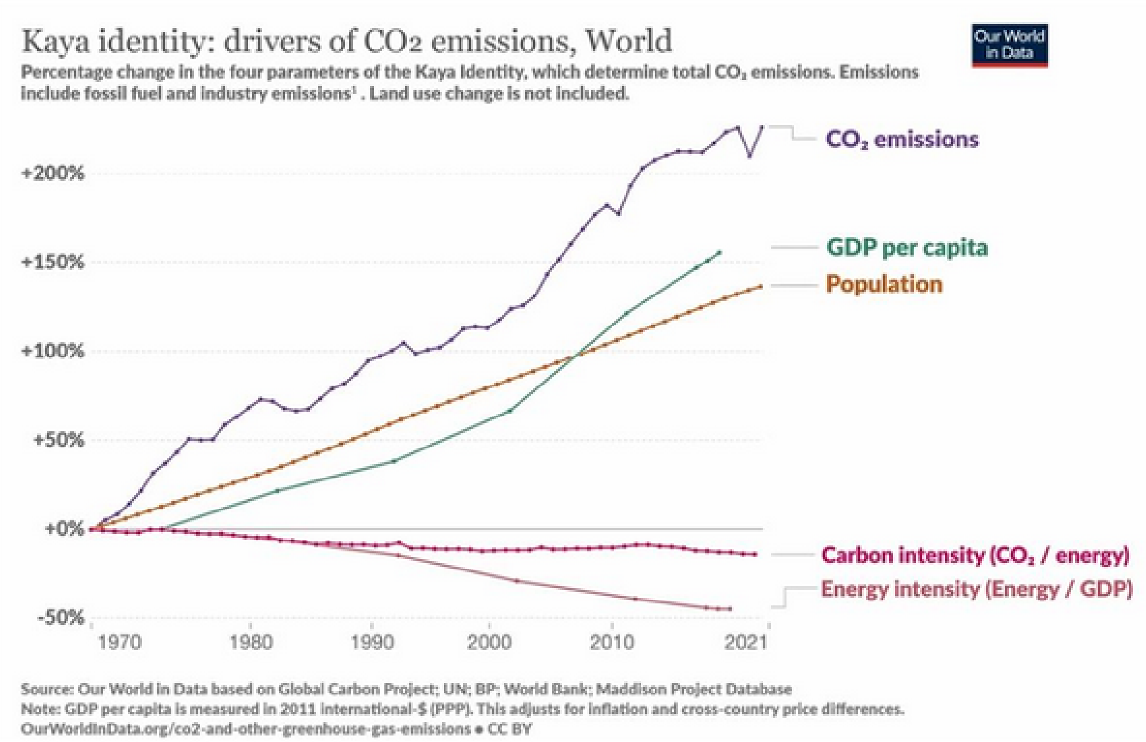


Figure 42: Kaya decomposition (worldwide)

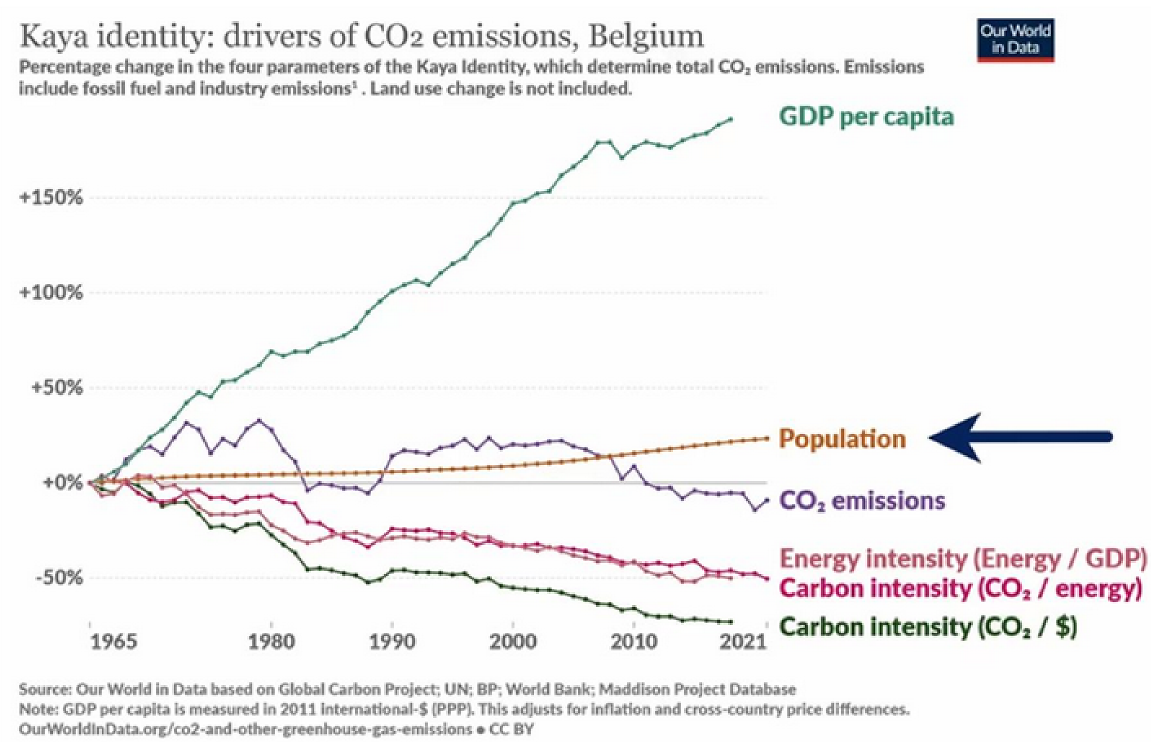


Figure 43: Kaya decomposition (Belgium)

10.6 Frameworks of sustainable development

Brundtland defines **sustainable development** as a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. In order to make the concept of sustainable development more operational, we will make a distinction between so-called weak and strong sustainability. But before we do this, we will first introduce the **different types of capital in economics**.

A first concept of capital is **physical capital**. This type of capital is the physical infrastructure (roads, bridges, ports, canals, but also data networks and so on).

The second type of capital in economics stems from labor, specifically the number of people and their skills. We call this **human capital**.

Furthermore, there is also the **natural capital**. This type of capital is generally linked with our renewable and non-renewable sources and level of pollution.

Lastly, we also consider the institutional or **social capital**. This is about the institutions, police, legal system, judges and so on in a society.

Now, we are able to define **weak sustainability**. A development path is called weakly sustainable if the total sum of natural, human, physical and social capital is not decreasing over time. If you use a weak concept of sustainability, then you basically allow for substitution between different compartments of capital. For example, it's possible that your natural capital is decreasing, but over-compensated by an increase in another capital stock.

In **strong sustainability** we require that each of the four capital stocks on their own are non-decreasing over time. So in that case it's not possible anymore that a decrease in one would be compensated by an increase in another capital stock. All of them have to be non-decreasing over time and there can be no erosion.

A first practical example of sustainable development is the **Adjusted Net Savings** by the World Bank. This concept tracks the evolution of different capital stocks over time on a country level. They make a distinction between the changes in physical, natural and human capital and then make the sum of these changes. If that total sum is positive, we can say that the adjusted net savings are positive and that this country is on a sustainable development track. Clearly, this is an example of a weak sustainability concept because we add the changes in the different capital stocks together. So a decrease in one can be compensated by an increase in another one.

Another example is the **doughnut economy concept** of Kate Raworth. This concept is visualized on Figure 48 and will be explained more detailed in Chapter 11. The outer ring is the environmental sustainability. The economy should not grow out of this environmental safe operating zone. The inner circle refers to the social aspect of the society and the justice elements. Society should not infringe upon the rights and the social and the justice needs of all the members of our society. Hence, this band basically defines the safe and the just space for society to operate in. Looking at the outer ring, we can clearly here see an example of strong sustainability, because this concept is about the safe operating zone in different compartments – biodiversity, climate change and so on – that the society should respect. So here we have an example of a concept that does not allow for trespassing the safe operating zone, and also it does not allow for compensation between the different types of capital in the society.

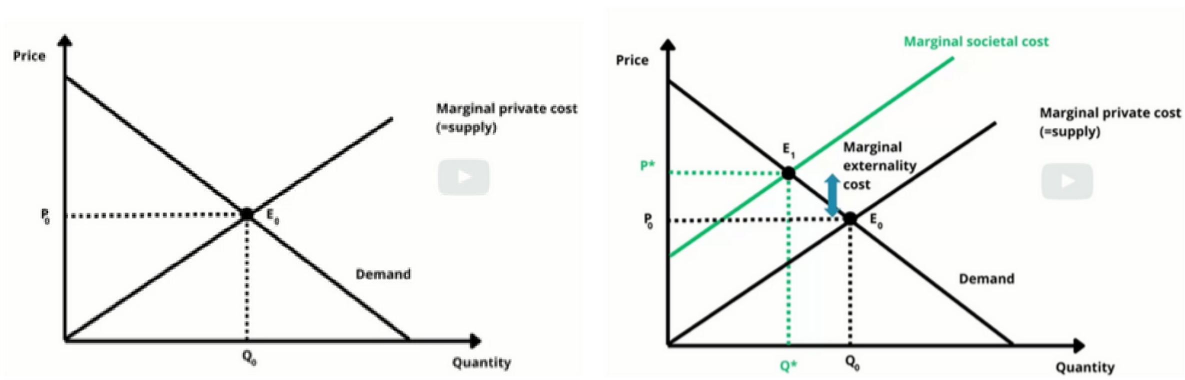
10.7 Externalities

In economics, we speak of an **externality**, if a production or consumption activity of an economic agent is affecting the consumption or production possibilities of another economic agent without full compensation being paid through the market mechanism.

An **example of influence of other production** is paper production that is affecting negatively the production possibilities of another production facility, the fish farm by dumping toxic chemicals and waste-water in the river, which then flows into the sea. Now imagine that downstream people are living along the river, normally enjoying a very nice scenic view on the water. But because of the water pollution, the water might be stinking and that is obviously negatively affecting the consumption possibilities of the home-owners. They can't enjoy a nice barbeque anymore in their garden, for example. So that is an **example of a production activity negatively affecting consumption possibilities**. This example also allows us to introduce the **compensation condition**. Imagine that the home-owner bought his house at a discount because he knew that it would be affected by this negative externalities by the bad smell of the polluted water. So he paid less than what he would normally do for such a nice house. That price discount is to some extent compensating for the externality. So if the price discount would be fully compensating the externality, then the discount is basically cancelling the externality, and we cannot speak any more of an externality. It's only when the discount is less than the value of externality, then there will still be some remaining externality. That is why this last condition of compensation is important in the definition of an externality.

Next, we can take a look at **how externalities influence the principle of a normal market of supply and demand** and how they can lead to market failure. **Market failure** means that the outcome of the market interaction is leading to an allocation that is not optimal from the point of society.

In a normal market of supply and demand, we will get a downward sloping curve for the demand of our product if we plot the quantity on the horizontal axis and the price on the vertical axis, like on Figure 44. The higher the price, the lower the bought quantity will be and vice versa. This is the demand side. The supply side is an upward sloping, marginal private production cost curve. This is reflection of the cost produce the product. Extra production requires extra input, hence an upward sloping curve. Without any government intervention or regulation, market equilibrium will occur at the intersection of demand and supply (point E_0 on Figure 44a). If externalities are present, the supply curve will be positioned higher than before. This result in a quantity that is too high ($Q_0 > Q^*$) and a price that is too low ($P_0 < P^*$) for what is optimal for society. This is shown by Figure 44b. We can say that the free market prices are not properly reflecting the marginal external climate change costs of production and that's why we end up with a market failure.



(a) Without externalities

(b) With externalities

Figure 44: Influence of externalities supply/demand market

10.8 Public goods

A **public good** is a good that is characterized by two crucial characteristics. The first is non-rivalry and secondly non-excludability. Public goods are **non-rival**, meaning that the consumption of that good by an individual does not reduce the amount available for others to consume of that good. A second characteristic of a public good is that it is **non-excludable**. It is not possible to prevent people from consuming the public good.

We can consider **lower emissions as a public good**. If countries reduce their emissions, that will lead to lower concentrations of greenhouse gases in the atmosphere and in the end, in the future, that will lead to less climate change. So that's clearly a benefit. This lower degree of climate change is a public good in the sense that it is non-rival. If one country like Belgium or Europe enjoys a better climate that does not prevent China or the US or Africa from enjoying a better climate. It's also non-excludable. Imagine that the US would not want to contribute emission reduction efforts to lower the greenhouse gas emissions, then still they can enjoy the benefits of a better climate.

This will lead to **free riding behaviour**. If an actor, a country, knows that it cannot be prevented from enjoying the benefits of a public good once it is provided, that makes it very tempting to refuse to contribute.

We can illustrate this incentive to free riding with an **example of two countries** that are thinking about joining and contributing to an international agreement of emission reduction: the USA and China. They both have the option to contribute or to free ride. This gives us the payoff matrix we can see in Figure 45. We can now discuss the 4 different possibilities from the point of view of the US. The first situation is the one where the USA free rides and China contributes. For the USA, this is the most desirable outcome. If the USA also contributes, we get situation 2. This is also desirable, because it as a positive effect on the emission reduction, but less than the first situation because now the USA also needs to contribute. If both countries are free riding (situation 3), there will be a bad outcome for the climate, but not for the countries themselves. The worst situation for the USA would be situation 4, where the USA contributes and China free rides. This payoff matrix can be used to determine what is the optimal strategy of the US to play in the negotiation game, based on the behaviour of China.

		USA	
		contribute	free ride
CHINA	contribute	2	1
	free ride	4	3

Figure 45: The payoff matrix between the USA and China

Given this urge to free ride, there is a strong reason to call for government intervention to prevent market failure. This works fine at the **national level**. We have national governments that produce a lot of public goods (think about defense and education, legal system, public infrastructure and so on). These public goods are financed it with compulsory taxation, paid by every citizen. However, at **international level**, we don't have those strong governments. So all cooperation on the provision of global public goods has to come from voluntary contributions and voluntary agreements like the Paris Protocol. That is why it will be very challenging to overcome this free riding incentive on an international level.

10.9 Elinor Ostorm

An important name in this field of research is Elinor Ostrom. Her research focused primarily on the management of local commons (or public goods). Her main contribution is that she shows that communities often succeed in managing commons in a sustainable way without government intervention.
Instead of the classic dichotomy between the market and the government, Ostrom showed that there is often a third option in which the users of a natural resource themselves set up sophisticated decision-making and enforcement systems to resolve their conflicts of interest. In this sense, her work complements the classical view that non-excludability inevitably leads to overexploitation of commons in the absence of government action. This classical view is called the tragedy of commons.

The numerous examples of successful and sustainable management of commons that Ostrom cites are usually about relatively small local communities such as a fishing village or a small farming community managing a common pasture or forest. In such communities, mechanisms, formal or informal or otherwise, often exist to enforce restrictions on the use of the natural resource. Those who do not comply with catch limits may risk being expelled from the community. And those who do not belong to the community may be denied access to the resource, sometimes by force. But for global commons with numerous potential users such as, for example, the atmosphere to emit greenhouse gases or tuna stocks in international waters, high coordination and transaction costs often prevent the emergence of effective management mechanisms. In such cases, the tragedy of the commons still looms.

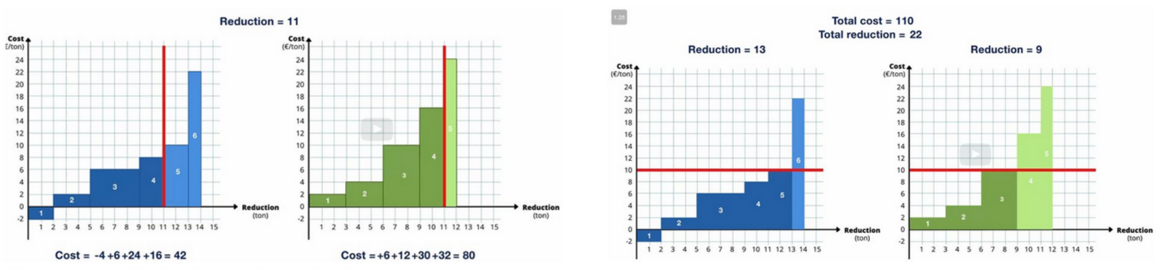
10.10 Environmental policy

We can conclude that externalities and public goods can cause markets to fail. That's why there is a need for public intervention to restore optimality. There are different ways governments can intervene in markets: **regulation, prohibition, subsidies, taxes** (and combinations of these).

10.11 Cost efficiency

In order to explain the concept of cost efficiency, we will first introduce the concept of a marginal emission reduction cost curve, or a so-called MAC curve. Typically, there are many, many different ways to reduce emissions and they typically differ in terms of the costs that they entail, but they also differ in the emission reduction potential that they can bring. A **marginal abatement cost curve (MAC)** is a concept or a device that helps you to trade off these different projects against each other.

We can compare two different ways to reduce emissions for the example case of 2 companies. The first way is to impose **identical reductions** to the 2 companies. Since the cost of the different reduction processes is not the same, the total cost for both companies will not necessarily be the same. In this example we can see on Figure 46a that the Green company has a cost of 80, while the Blue company only has a cost of 42. A better way would be to base the reduction on **marginal cost**. Using this way, the Blue company will need to do more effort than the Green company, but the cost will be the same for both companies. This way is shown on Figure 46b.



(a) Identical reductions

(b) According to marginal cost

Figure 46: Total cost when imposing two different ways for reduction

10.12 Price based instruments versus legal standards

A big difference between price based instruments and standards is that **price based instruments** are more **cost-efficient**. This means that the total cost to society to reduce emissions to a given level is as low as possible. Legal standards are in most cases not cost efficient because it's very difficult for a regulator to know of each company its individual technology options. Usually the regulator will use a sector average to define the emission standards. And so that leaves a lot of options for cost savings aside.

A second criterium to look at when it's about the choice of policy instruments is **dynamic efficiency**. If you are confronted as a company with a emission tax on your remaining emissions, that means that every year you are reminded of the cost of this remaining emissions. So every year you get the signal that there are perhaps other options to reduce your emissions even further, because perhaps new technologies have come on the market to reduce your emissions or existing technologies have become cheaper. So you are continuously reminded that there are perhaps ways to improve your environmental performance, because you are all the way you are every time you are taxed on the remaining emissions. That is very different with the emission standards.

Hence, we can conclude there is a difference between price based instruments and legally enforced emission standards in the sense of dynamic efficiency and static cost efficiency. In both cases, we see that price based instruments perform better than legal standards.

10.13 Green tax reform

When a government introduces carbon tax, we will notice that the tax triggers users to implement reduction projects, but it also can be used with a sustainability impact.

The government could use some of the carbon tax revenue in order to give subsidies to households to invest in solar PV on their rooftop or to help companies to build wind turbines or to invest in energy efficiency of their installations.

A second possible use of the revenues of a carbon tax is to invest in social policy. And that can be very important because we know that introducing a carbon tax is typically regressive. With regressive we mean that it can make the income distribution even more unequal. The reason for that is that energy related expenditure related to fossil fuels are, in percentage terms, more important for poor households in their budget than the share of that in rich household budgets. So if we then introduce a carbon tax that will weigh more heavily on the shoulders of poor households rather than on the rich ones.

A third possible use of the tax revenue of a carbon tax is to use it for labour market policies. In a lot of European countries we are seeing very high rates of labour taxes. And this is giving a disincentive for people to go out working and also giving a disincentive to employers to create new jobs. So this is holding back a lot of economic activity.

The **double dividend** is the idea that by combining a carbon tax with lower labour taxes, we can achieve a win-win situation. A first dividend is lower environmental pressure, lower emissions, a better environment because of the taxation of carbon. The second benefit or dividend has to do with the labour market. Because we invest the revenue in lower labour taxes, we will see more jobs. So better environment combined with more jobs.

The general idea for green tax reform is tax bads (carbon dioxide or other environmental pollution problems) and not goods (for instance, labour).

10.14 Taxes versus subsidies

Taxes and subsidies, disencouraging the bad and encouraging the good alternative seem equally effective, but they are not. There are two rebound effects we can notice. The **first rebound effect** is that subsidies are partly effective, but miss the underlying consumption activity. Think about giving subsidies for electric cars. This will give incentive to green behaviour, but doesn't give disincentive for private mobility, which is the underlying consumption activity. The **second rebound effect** is that subsidies are an extra budget that may be used for carbon intensive activities. Think about giving big subsidies to households, which can give them incentive to use the additional budget to go on a trip to Barcelona for example.

This is not the only problem with subsidies. Subsidies should trigger investments that would not be taken without subsidies. In reality, this is not always guaranteed. This is the problem of **additionality**. Another downside to subsidies is **the Matthew effect**. Subsidies should impact the poorer part of society, but the often have higher impact on the richer part. Furthermore, subsidies are expensive for governments, and often lead to higher taxes, especially on labour.

Before we conclude if taxes are better than subsidies or not, we will take a look at existing environmentally harmful subsidies in our tax scheme. A first example of bad subsidies or bad tax exemptions are salary cars. Employees are given cars almost free (and with a tax exemption) from their employer, which is nice, but leads to a lot of additional traffic, traffic jams, accidents and also emissions. Another example are the subsidies for non-sustainable agricultural activities. Getting rid of these subsidies would be a start in the right direction.

Another step is a carbon tax improvement. Right now, different energy consumption are taxed in different ways because they are submitted to different tax systems. Because of this, 30% of energy use is not taxed, while others are taxed at high rates.

10.15 Link with other challenges

Since economics and sustainability are such broad topics, we can find a lot of links with the other domains we studied earlier. A first link we can find is one with **climate and biodiversity**. The market uses to much fossil fuels because its negative externalities are not taken into account and it does not provide enough effort for biodiversity because its positive externality is not taken into account. Furthermore, the principle of freeriding makes greenhouse gas reduction very difficult. We can also find a link with **demography**. A better economy will lead to a higher GDP, which will lead to a higher population and higher emission/capita, which will then result in higher CO_2 emissions. It is difficult to avoid this chain. The third link we can find is the link with **buildings** and **mobility**. The market brings too much car traffic because negative externalities are not taken into account. Smart road pricing might be a solution for this problem. Secondly, subsidies for salary cars are an example of bad subsidy. Another link we can find is the one with **raw materials** and **circular economy**. The market leads to lots of material extraction because negative externalities are not taken into account. There also is a deposit refund system for one way packaging. The last link we will cover is the link with **energy**. PV, battery and electric car subsidies suffer from the Matthew effect. Also, the energy of heating households is not taxed in a good way. The taxation of all energy carriers should be aligned with full social cost.

11 Social and economic inequality

11.1 Study guide

Module 11 sketches basic insights into inequality both within and between countries. Make sure to understand:

- Inequality as a multi-dimensional concept: you can't express inequality in only a single number or indicator
- Sources of inequality (according to philosophical literature): fate, personal choice, social circumstances + which is considered problematic
- Inequality between countries versus inequality within countries
- Main criticism of Philip Alston against the World Bank's definition of the International Poverty Line
- Different drivers of inequality:
  - What the theory says about the effects of neoliberal globalization on the evolution of inequality, and why reality proved partially different
  - The increasing concentration of capital: understand the differences between wealth inequality and income inequality. Understand what r > g means in this respect, and how it can influence the way societies function (concentration of power, land robbing)
  - environmental and climate disruption: poor people often live in the most polluted areas and are at the same time more often dependent on their natural environment (grazing, farming,. . .)
- Reasons why we should be concerned about inequality (also beyond the mere ethics): link with human rights, link with economic development, link with environmental sustainability, societal well-being, political stability
- Policy solutions (and the link to the drivers)
- Kate Raworth's model of the doughnut economy

11.2 Inequality as a multi-dimensional concept

Inequality is all about some people having more than others and refers to rankings on quantitative scales. It is very difficult to pinpoint what we should use as a yardstick for such a scale. We can use financial measures, but then there are still lots of possibilities. If we take the net disposable income, we need to consider differences in size and composition of households and even if we balance this scale, we need to consider that each household can have different assets. But there is more to it: the living standard of a person or household also depends on their access to collective services like education or culture, their schooling and skills, their health, their network of friends, their participation in social life... All these items can be considered resources – material as well as immaterial. In other words, inequalities are multidimensional.

11.3 Sources of inequality

In the philosophical literature, a distinction is usually made between three sources of inequality: fate, personal choice, and socio-economic environment.

Firstly, **fate** refers to inequalities that are due to some natural condition beyond the power of men: the most typical example here is differences in innate abilities. Some people are born very talented, others are not. Even the most democratic education systems will not wipe out these differences. Society could try to compensate for their income differences, but not their differences in learning abilities and skills. The same argument could apply to innate differences in health, psychological condition etc.

Secondly, **personal choice** may affect inequalities, simply because people have freedoms and diverse preferences: some are workaholics while others are Zen; some hate to study while others cannot get enough of it; some are entrepreneurial while others are epicureans. It is impossible to impose uniform rules as straitjackets to avoid these inequalities, nor even the differences in material welfare that go in pair with them.

It is the third source of inequalities, **social circumstances**, which is commonly seen as problematic. You cannot choose the cradle in which you are born nor the wealth or skin colour of your parents, and yet all too often those conditions determine your odds in life to a large extent. The overwhelming majority of the population would agree that neither your socio-economic or ethnic background, nor even the region where you grow up can be accepted as legitimate sources of inequality. These are beyond the scope of individual choice, but within the scope of collective choice. Therefore, from a moral point of view, society (and the government) are deemed responsible for the minimization of these sources of inequality.

11.4 Inequality between versus within countries

Inequality between countries stems from the fact that there is a difference between the wealth of rich (First World) countries and developing countries. Within these countries, there is also inequality between people. This inequality can have a lot of reasons, such as social status or education level.

11.5 Main criticism of Philip Alston

There are 7 key takeaways from Philip Alston's criticism:

1. **There has been a 'dramatic and longstanding' neglect and 'downplaying' of extreme poverty** by many governments, economists, and human rights advocates.
2. **The claim that extreme poverty is nearing eradication is unjustified.**
3. **Using a more defensible IPL generates a radically different picture.**
4. **The impact of COVID-19 will be long-lasting.**
5. **While the SDG process has been a 'game-changer' in important ways** and has been used to very good effect in many settings 'promoting awareness, galvanizing support, and framing the broader debate around poverty reduction' and often providing 'the only available entry point for discussions of contentious issues', 5 years after their adoption it is time to acknowledge their failings and the 'deeply disappointing results to date and a range of new challenges.'
6. **'Continued large-scale global poverty is incompatible with the human right to an adequate standard of living, and the right to life alongside the right to live in dignity.** The failure to take the necessary steps to eliminate it is a political choice and one that leaves firmly in place discriminatory practices based on gender, status, race, and religion, designed to privilege certain groups over others.'
7. **'To avoid sleepwalking towards assured failure while pumping out endless bland reports, new strategies, genuine mobilization, empowerment, and accountability are needed.** Recalibrating the SDG framework itself in response to fundamentally changed circumstances is an urgent first step.'

11.6 Drivers of inequality

The three biggest drivers of inequality that played a key role in the past decades and still mater today are the neoliberal globalization model, the increasing concentration of capital, and environmental and climate disruption.

The **neoliberal globalization** has a strong economic underpinning, based on free trade as an engine of global prosperity. In open competitive world markets, whoever can produce a good or service cheaper than others will see their exports grow. Likewise, whenever imported goods are cheaper than those that are produced locally, consumers will benefit from lower prices under free trade and see their purchasing power increase. In a diverse and globalized world, all countries will tend to specialize in their most competitive sectors and reduce their production of other ones, which results in efficiency gains, economic growth and less poverty on a global scale. Rich countries will tend to specialize in capital- and knowledge-intensive sectors such as pharmaceuticals or financial services, while developing countries have an advantage when specializing in sectors that use their abundant low-qualified labour, such as agriculture or textiles. The theory also predicts a downside, however: namely, greater inequality in rich countries. Their specialization mainly benefits capital owners and the highly educated, while the imports or outsourcing of low-skilled-labour-intensive activities undermine the job opportunities and incomes of their own low-skilled people. In contrast, developing countries would only benefit from free trade because they can specialize in labour-intensive sectors, which employ many low-skilled people. This should lead to a more equal income distribution in the South. This is the theory of the effects of neoliberal globalization on the evolution in inequality. In reality, there are also developing (mainly Latin-American) countries where poverty and inequality have increased. The reason for this is that free trade can only thrive in a context of equality between the parties involved. This assumption obviously does not fit with reality. Rich countries have used their power to negotiate unbalanced trade agreements. They have pressurized developing countries to open up their markets, while protecting their own markets in the North.

Next, we look at the **increasing concentration of capital**. First we must understand the difference between income inequality and wealth inequality. Income is a 'flow' concept: it is a revenue linked to a particular time period (e.g. a year). Income inequality refers to the unequal distribution of income among a population. It focuses on the disparity in earnings or income levels among individuals or households in a particular area or society. Wealth, on the other hand, is a 'stock' concept, measured at a point in time (e.g. December 31st). Wealth inequality pertains to the uneven distribution of assets and possessions (wealth) within a population. Wealth includes not only income but also property, savings, investments, and other forms of accumulated assets. Figure 47 depicts the difference between income and wealth inequality. In 'normal times', the return to capital assets (r) appears to systematically exceed the rate of economic growth (g), so $r>g$. Assuming that the working population see their income grow at a rate g, along with overall economic growth, while capital owners see their assets grow at the higher rate r, the gap between the rich and the rest of society may keep widening indefinitely. There are some dangers connected to this tendency. Firstly, the concentration of wealth in the hands of a small group goes hand in hand with a concentration of power, which can be a threat to democracy. Secondly, there is a link between the concentration of financial capital and runaway speculative capitalism, which seeks profit through investments in land and real estate rather than through productive investments. This has led to 'land grabbing', robbing of land and water resources from rightless poor populations, violent evictions and deportations of entire villages, housing market bubbles and financial crises, deforestation and environmental disasters, and corruption.

The last main driver is **environmental and climate disruption**. The world's poorest people live in the most difficult environmental conditions. At the same time, the world's poorest are highly dependent on their natural environment (like forest, grazing land, or water). On top of this material vulnerability comes the weak political and legal status of the poor. They often have no legal protection and no voice, which leaves them powerless against environmental crimes by large corporations, or even against their own government. Climate change reinforces the environmental damage. The annual damage from environmental disasters such as hurricanes, forest fires, droughts and floods already runs into tens of billions, and the bulk of that loss is suffered by the lowest-income groups, especially farmers. According to the UN, by 2030 already, climate warming would lead to an increase in extreme poverty by at least 120 million people.

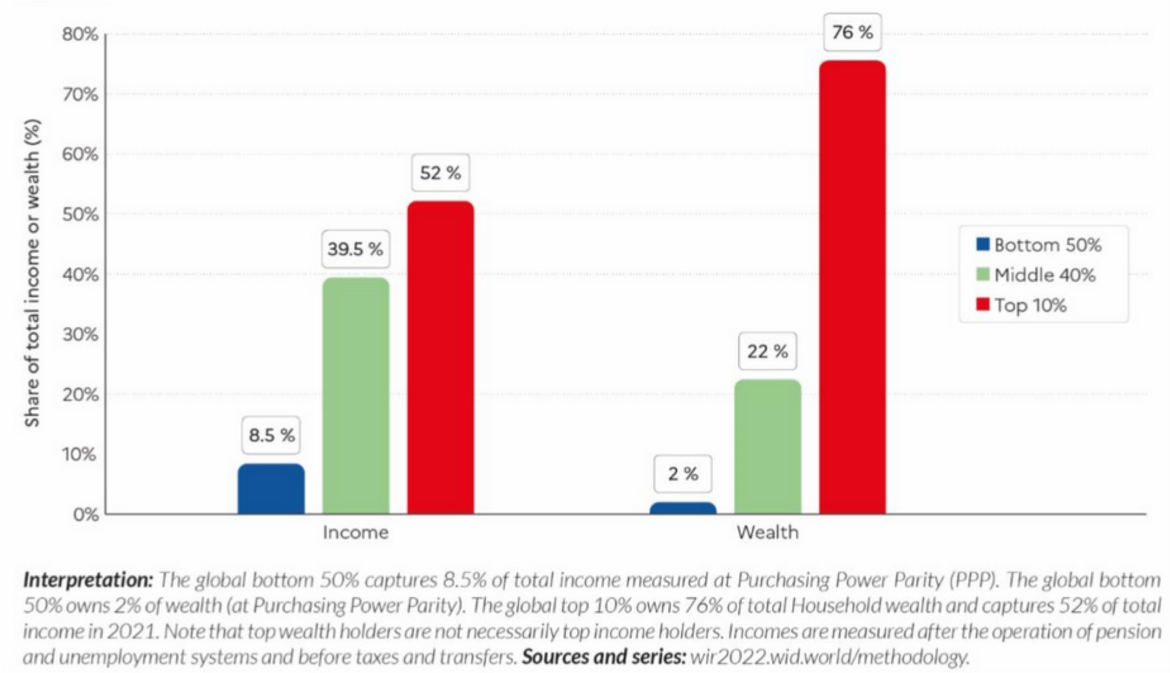


Figure 47: Global income and wealth inequality, 2021

11.7 Concerns about inequality

The mere ethics are not the only reason why we should be concerned about inequality. There is also a link with human rights, economic development, environmental sustainability, societal well-being and political stability.

First and foremost, we should recall that the Sustainable Development Goals are rooted in **human rights**. For a lot of SDGs, there is a one-to-one relationship with articles from the Universal Declaration of Human Rights. Malnutrition, child mortality and suicides of bankrupt farmers are clear indications that these rights are far from being realised. Eradicating extreme poverty is therefore rightly the very first SDG.

Moreover, it is worth emphasizing that inequality and poverty are cross-cutting issues in all other global sustainability areas. **In addition to the economic realm (income, work, tax policies, international trade etc.) there are clear links with all dimensions of social life (education, healthcare, social participation, political voice) as well as with all planetary challenges (energy, natural resources, the environment and climate change).**

Based on extensive statistical analysis of correlations between indicators of income inequality and indicators of unwellness in western societies, Wilkinson and Pickett claim in their famous publication 'The spirit level' that inequality is not only a problem of the victims, but of the whole population. More inequality has an impact on the **societal well-being** and is associated with lower social mobility, more crime, less confidence, poorer physical and mental health of the population, up to and including more addiction problems. The authors stress that even individuals from affluent groups suffer to some extent from inequality. They attribute this to socio-psychological effects such as stronger feelings of insecurity, of status competition, fear of being judged negatively by others, and a lower sense of belonging.

Finally, inequality poses a threat to **political sustainability**. The increasing concentration of capital (and related power) in the hands of super-rich people poses a serious threat to democracy. Indeed, one cannot expect all super-rich to act ethically pure.

11.8 Policy solutions

A first solution relates to fairer globalization. Remarkably, Oxfam, the leading non-governmental actor in the development debate, does not argue against free trade but for fairer free trade. In doing so, Oxfam challenged the EU to further reduce its own import tariffs and export subsidies towards developing countries. Fair free trade even implies that poor countries should retain the right to protect weak sectors as long as necessary to prepare them for international competition. The use of fair trade labels helps to inform consumers on the ethical aspects of international trade.

The second policy strand deals with capital markets. Piketty's wants to combat extreme concentration of wealth. A key tool for this is a progressive tax on big fortunes. In the past decades, large-scale tax evasion by the most wealthy people as well as multinational had become a genuine plague. Thanks to multilateral agreements on the exchange of financial information, governments are beginning to get a grip on big wealth, and the feasibility of wealth taxation is increasing.

A third set of policy prescriptions relates to the environmental and climate agenda. Our review of determinants of inequality shows how closely that agenda is intertwined with global redistribution - or at least, preventing inequality from derailing. The World Bank, for example, has calculated that limiting climate warming to 1.5 rather than 2 degrees could save hundreds of millions of people from poverty. Obviously, achieving this objective through 'climate adaptation' does come at a cost, which needs to be financed in a fair and solidary way.

In addition to global-level strategies, more fine-grained and targeted strategies are of course also needed. The basic needs strategy focuses on the implementation of all the basic rights that the SDGs also refer to: right to food and water, health care, education, decent work and so on. Education has a particularly high social and economic return in developing countries, as it not only provides useful knowledge for the farm or labour market, but also 'life skills' that contribute to better health, social cohesion, gender equality, civic responsibility and democracy. Summing up The combination of the above strategies soon brings us close to Kate Raworth's 'doughnut economy'.

11.9 Kate Raworth's model of the doughnut economy

Kate Raworth does away with the dogma of endless linear growth. She advocates a circular economy that, while growing according to human needs, remains within the limits of what the planet can handle. In the image of the doughnut (see Figure 48), the inner circle refers to the minimum prosperity needed to guarantee the basic rights of every human being (food, housing, education, health, social participation and so on), while the outer circle represents the maximum limits of planetary sustainability. The key, therefore, is to keep the economy in balance between these minimum and maximum limits. The basic circular pattern of the economy seeks to ensure that any form of 'waste' can be reused, in order to spare the environment and climate.

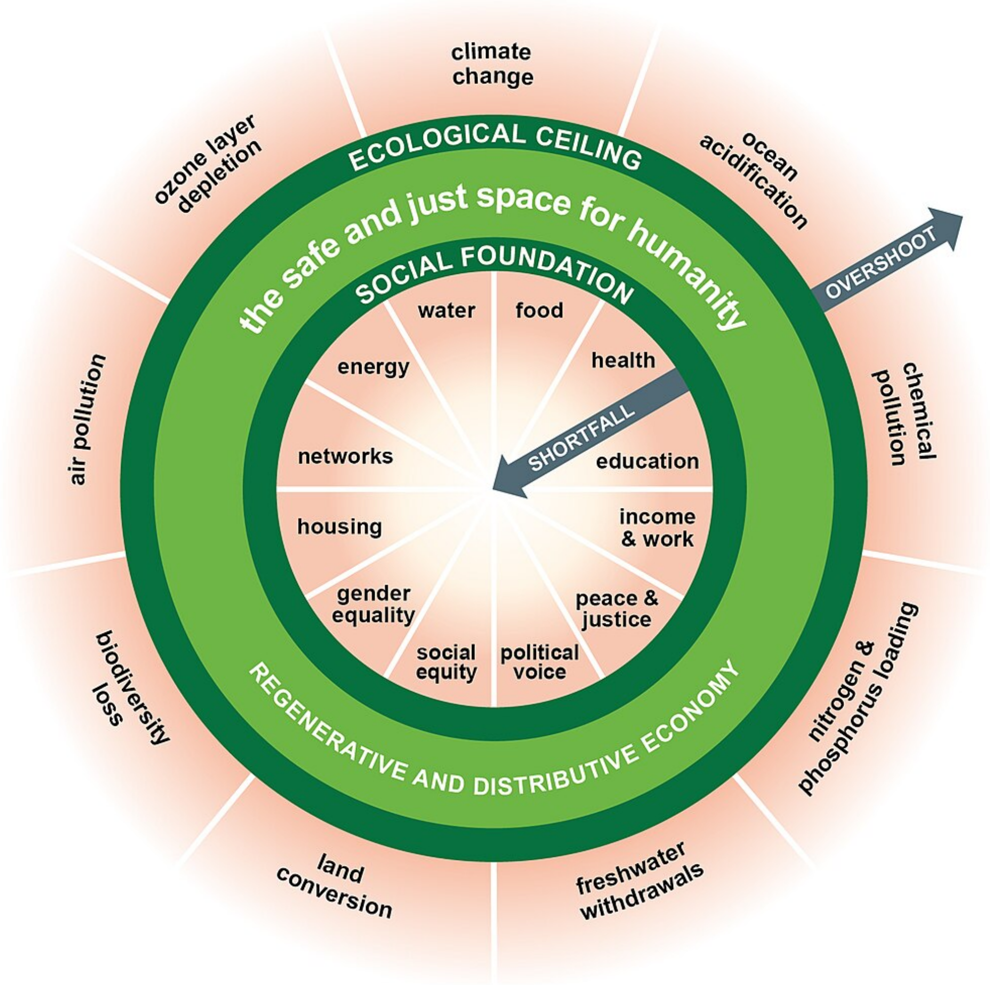


Figure 48: Kate Raworth's model of the doughnut economy

12 Human behaviour

12.1 Study guide

A lot of the discussed global challenges and their solutions require a lot of change in behaviour from us humans. This however, is not easy. Because of this it's important to understand how the human brain works, what drives us and what motivates us.

We will first explore the way in which we make decisions when faced with different dilemma's or situations. Once we know more about this, we can take a look at how to change these thoughts and convince people. Finally, we will take a look at how biasses affect our thinking.

12.2 Conditioning vs. motivating

12.2.1 Conditioning

Edward Thorndyke was one of the most important psychology researchers to live. He started his career at Harvard studying "the instinctive and intelligent behaviour of chickens". Moving on to the study of cats at Columbia University. In his experiments with cats, he deprived them of food and let them solve some sort of puzzle to get access to food. When he would repeat this sequence with the same cats, he noticed they would very quickly catch on to the solution, and by the third repetition, they could solve the puzzle in a matter of seconds.

Similar and systematic experiments gave way to the **law of effect**: 'responses that produce a satisfying effect in a particular situation become more likely to occur again in that situation, and responses that produce a discomforting effect become less likely to occur again in that situation'.

Later on this law was studied by **Boris Frederick Skinner**. He showed how rewards were best handled to learn new behaviour in rats, mice, pigeons, pigs and other species of the animal kingdom. He also pioneered a way to prove learned behaviour by systematically withholding rewards.

The act of learning and unlearning was central in psychology research for many decades. Thousands of papers were written about the effectiveness of rewarding because it was a good motivator in the tested animal groups.

12.2.2 Motivation

When it comes to **rewarding behaviour**, a complication is that people overestimate the importance of **extrinsic motives** in the behaviour of others, while they look at their own behaviour as more **intinsically motivated**.

A study by Chip Heath illustrated this by asking people to rank the order of importance of eight motives in their professional life. The first four were extrinsic: pay, benefits, praise and security; the four others were intrinsic: learning, developing, skills and feeling good with worthwhile work. On average, the first four out of five were intrinsic motivators, pay was only ranked on the fourth place.

When the participants were asked to do this for their peers, pay moved up to the second place. Going even further, when they were asked to do this for their managers or bank clerks, they ranked pay on place one. Those same managers and bank clerks only ranked pay on position seven for themselves.

Because of these insights, most psychologists think of rewards and sometimes punishment to aid behavioural change in people. But getting people intrinsically motivated for change is more qualitative and at least as important as the reward structure.

12.3 Social dilemmas

Psychologists use certain experiments as **a paradigm to study social dilemma's**. An example of this is a game where there are a green card and a blue card. You and seven others need to choose a colour without knowing what the others will do. Choosing the green card yields you five euros, if you pick the blue card you get 24 euros, but everyone gets a fine of 3 euros.

This game has parallels to the consumption of meat and climate change. If everyone would eat less meat, it would have a huge impact. But is an individual person willing to let go of this steak for this goal? Many other situations follow this train of thought, like watering your lawn so it looks good during a drought. Picking the blue card while everyone else picks green is advantageous to one self, choosing green would make the whole group better of.

These types of paradigms are all derived from the **prisoner dilemma**: imagine that two people, A and B, commit a crime. The authorities know this but don't have the proper evidence. They get interrogated and given the choice to confess or not to confess without knowing what their respective partners will do. The outcome of their decision is depicted in figure 49.

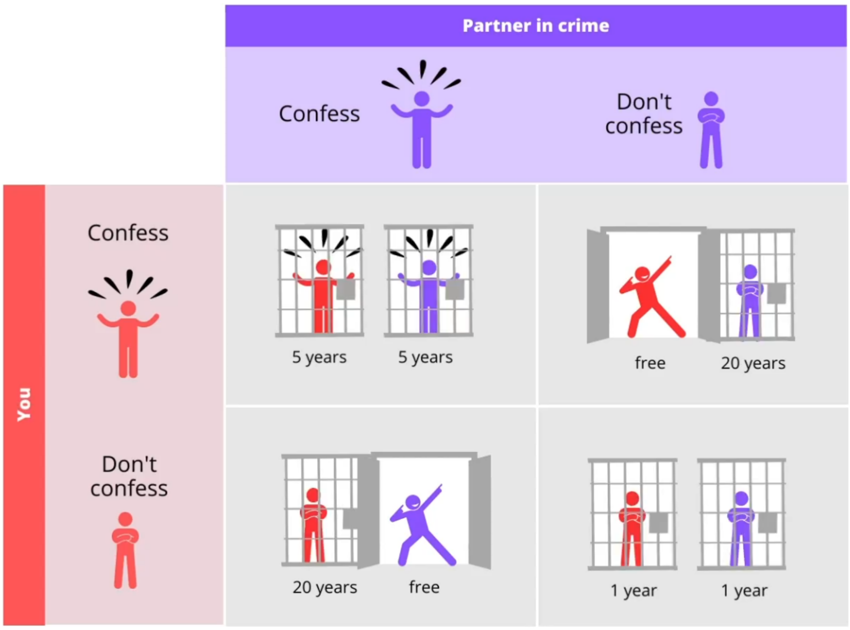


Figure 49: depictions of the outcomes for the prisoner dilemma

What must one do when faced with this situation? It really depends on what your partner does. But in general it is better to confess, this minimizes the chance of you going to prison for a long time. On the other hand, not confessing would lead to the minimal amount of jail time between them.

In the prisoner dilemma, the participants are not anonymous, they each bare a large responsibility towards the outcome of the situation. When talking about climate change and meat consumption, this is not the case. There are many parties involved which makes it completely different.

Going back to the card experiment we can now find some meaning in a social dilemma. Going with the green card is called a **cooperative choice**, while the blue pick would be called a **competitive choice**. A number of factors have been experimentally shown to have an effect on the results:

1. It is important that people thoroughly realize the mutual dependence in the situation. This grows when consecutive choices have to be made with feedback about the results after every choice. Awareness of the impact one has is very important.
2. The number of parties involved in the dilemma affects cooperation. The more participants, the more competitive choices will be made. This is because people try to ride free on the cooperative choices others make.
3. Communication promotes cooperation.
4. Cooperation decreases when the choices are made by groups instead of individuals. This is because a sort of 'us' vs 'them' mentality crops up.
5. Competition decreases when individual choices are more visible. This is because nobody wants to be perceived as the bad guy who ruins it for the rest.
6. Research points to important individual differences among types of participants

12.4 Individual differences

The research for individual differences is mainly based on three types of studies: publicly available information, experimental research and questionnaires.

The **New Ecological Paradigm** by Riley Dunlap is an example of such a questionnaire. It states a number of prompts and asks the participant to rate the extent in which they agree with them. It is shown to be a reliable and accurate way to gain insight into opinions and behavioural intentions. The results of the questionnaire about climate show the following interesting correlations:

Relevant knowledge The more ecologically literate one is, the more inclined they will be to make more sustainable choices.

personality traits Research has identified five personality traits that describe a personality accurately. The latter three correlate well with environment-friendly behaviour:

- extroversion
- neurotic-ism
- agreeableness
- openness
- conscientiousness

Gender In general, women are more concerned about the environment and nature than men.

Education and ocupation Lower educated people are not as used to having an influence and being able to choose, so they are less attached to it.

beliefs and values In the USA, political affiliation is a better predictor of global warming-related behaviour than education and scientific knowledge. Furthermore, there is a strong correlation between religiousness and sustainable behaviour.

Materialism There is a negative correlation with materialistic people and climate.

External locus of control people who attribute successes and failures to luck rather than their own effort display less sustainable behaviour than people with an internal locus of control.

12.5 Thoughtful or automatic

The human mind has long been thought of as rational, and economically conscious. This was extended to thinking that if we provide the right information about sustainability, people would take action for the better.

This, of course, is not true. **Daniel Kahneman** makes the distinction in his book **Thinking Fast and Slow** between **two thought processes** or two systems. **System two** is the very rational process that we associate with the human mind, it is the second system because it is submissive to the first system. This **system one** is the dominant process and represents the unconscious thinking. System one is a lot more energy efficient since it happens unconsciously. They are very fast but tend to fly under the radar as we are not aware that we have this thought process.

For example, watching a video is something handled by system one. It does not take a lot of effort to process the visual and auditory information presented to you. Interpreting what is actually happening is a job left to system two, this takes a lot more effort. Another example is riding a bike, while learning, this task is handled by system two. As you make more progress and get comfortable with it, cycling gets handed over to system one which frees up system two to do other tasks.

If something like riding a bike can be automated into a system one process, we can leave other complex tasks to the highly automated system one as well. For example communication is handled by system one as well. This means that a lot of information – including sustainability – flies under the radar when we don't actively process it with system two.

Another sustainable example is the issue of rising energy prices. With purely rationally thinking brain, insulating your house is a no no-brainer. However, this is a long term economical issue which flies under the radar with system one. This has a dramatical impact on the rate at which people insulate their homes. A solution for this problem is to incentivize people with subsidies, not only for the act of insulating but also for removing barriers to insulate such as cleaning up the attic.

Similarly, for instance, with regard to sustainable mobility, we also see that car owners engage in all these system one type of processes that make them stick to their car driving habits. Rather than making the rational decision and understanding, for instance that public transport or bikes might be the much more efficient way in terms of time or cost, they stick to their cars.

12.6 Persuasive communication

Because we know people mostly process their thoughts unconsciously, we can assume this also applies to communication processes as well. **Predominant unconscious processing** means that the sender of a message will be using a lot of intuition when sending messages to others. The receiver will then use their own cognitive intuitions to process these messages.

When a sender is invested in the message, they will consciously think about how to relay it in order to motivate a receiver. At the same time the receiver will have their own ideas and biasses about the message, influencing about how they act upon it. There are two types of messages processed by the receiver: **persuasion** and **rhetoric**. The former is what's going on on a day to day basis with hundreds or thousands of messages. The latter are messages which the receivers really think they should take time for. The difference between these two holds the key to behavioural change.

If we want people to think differently and behave other than they are now, we have **two different sets of drivers to make that behavioural change**.

Conscious drivers Legal restrictions, rhetoric campaigns... . Can influence conscious system two behaviour (only works if someone actually listens and pays attention)

Unconscious drivers persuasion, the design of the situation that you are operating in... can influence unconscious, system one behaviour. (change your mind little by little)

These changes should always be looked at in a combination, because it will always be more effective if both systems are aware and cooperating about the intended behavioural change.

12.7 Stakeholder system

With the knowledge of how people communicate as both sender and receiver. We should revisit the way in which we think about communication, where the sender sends a message to the receiver with a potential for noise to slip in as seen on figure 50.

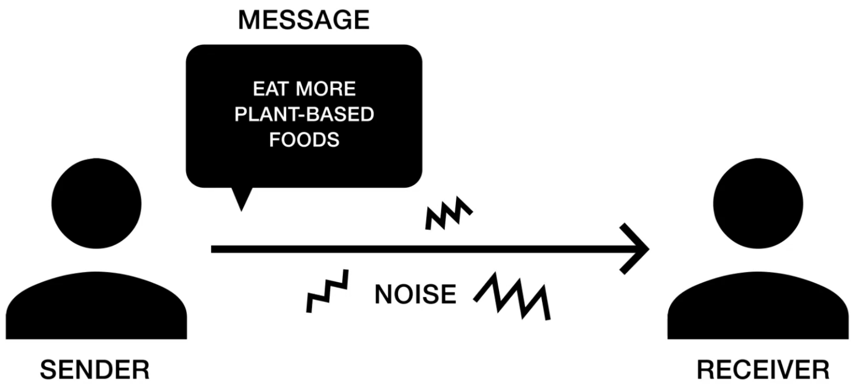


Figure 50: Dated sender receiver model

This however is not accurate because it doesn't take system one into account. We use it to kind of filter all the different messages we receive, which makes us not pay any real attention to a lot of the messages. We want to divide our communication time between a lot of different things. This means your message will just be one message in a whole range of them. It is thus important to understand that a receiver will probably not devote a lot of time to your particular message.

It is much better to represent communication as a **stakeholder system** such as seen in figure 51.

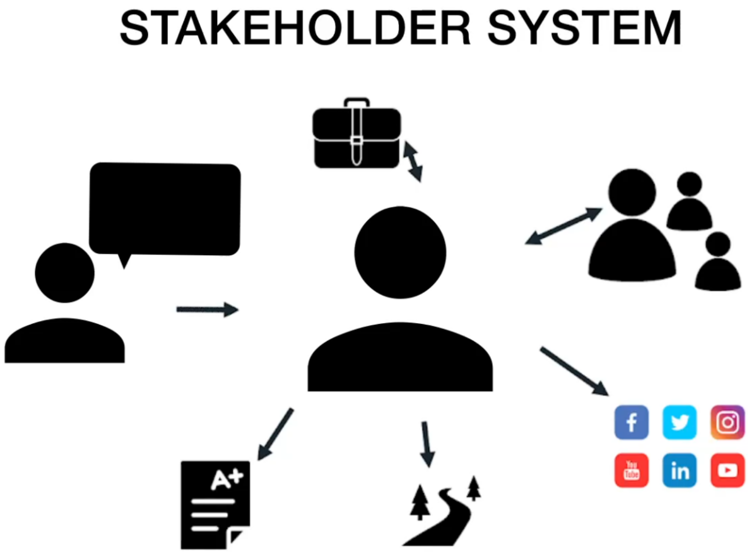


Figure 51: Stakeholder model

In this system there is one receiver with a lot of senders over different mediums. This means that there is a lot of competition between senders to get their message across to the receiver. **It is important that every stakeholder gets a win for the system to work best**. If the recipient wants a message, they go to a medium to accommodate this which is a win for the receiver. Vice versa, the medium wants recipients because otherwise it really isn't a medium any more. A medium also needs recipients to please advertisers which may be involved. So the main stakes for the medium are to have recipients, but also senders and maybe advertisers that finance and at the same time also populate the medium.

As a sender you want to reach recipients, often you will have to go through a medium for this. So your win is a cooperation with the medium and reaching out to recipients. Crafting a good message is thus not the only requirement, the choice of medium is also very important. And **if you then think about the best win situation for all stakeholders involved, then you're going to have the best possible chance of getting your message to the recipient in circumstances that you might prefer**.

12.8 Biases

Biasses are mental short-cuts that people take when they consider information and communication. They are important to take into account within the communication process. On the sender side, the illusion of attention and or communication with the receiver is a common one. **George Bernard Shaw** famously said that "The single biggest problem with communication is the illusion that it has taken place". When looking at this illusion we should not only think about the message as a whole but also the contents of that message.

For instance, climate activists throwing a can of soup over a painting makes sure a lot of people see their message, but the content of their message is usually completely lost because of the way they chose to convey their message. So that's **a double layer of the illusion** of communication. And that double layer – or that attention to the message, but not its content – has also been demonstrated in a set of experimental studies.

Even if people are noticing your message, they might fail to notice what's in it. This implies that messages sent out to receivers are not always received and if they are received, that they are not always processed as deeply as we think they would be processed. Because, for instance, the packaging of your message might distract them from the contents of your message.

12.8.1 Norms

Norms are an incredibly persuasive driver in communication, we are influenced a lot by them. This can be explained by our tendency to be influenced by a group because that helped our species survive and evolve into who we are now. There are essentially two types of norms we have to think about: (see figure 52 as well)

Injunctive norms These are norms which say what you should be doing to be accepted in a group. This is what we typically think of when we think of norms.

Descriptive norms These are the perceptions that we have about what others do or what we even just think they are doing. They might sometimes be in contrast with injunctive norms.

Figure 52: Two different types of norms

These norms work in opposite directions so they can have a large effect on the message you are trying to convey. To complicate matters more, the **perception of those norms** have an influence as well. So it might not even be the reality that influences us, but our perceptions of that reality. It's **perceptions of descriptive norms that are a very powerful driver** and that are often neglected when we try to persuade other people.

12.8.2 Return on investment biases

When we put effort, time, energy or money into something, we usually do it to have a greater return at the end of the ride. There are a few biasses which have an effect on the way we think about these kinds of things.

Sunk cost fallacy This is when we let past investments influence future decisions. Instead, we should focus on current circumstances and make choices based on what makes sense now, regardless of previous expenses. For instance, replacing a relatively new car with a more suitable transport option is rational, even if it means letting go of the initial investment. The key is to prioritize present and future benefits over past costs.

Endownment effect We tend to place higher value on things we already own or decisions we've made in the past. This is because we see them as part of our identity and life. Consequently, we often resist letting go of them, even when it might be more rational to do so.

Loss aversion People avoid the psychological impact of loss and tend to value it more than a comparable gain. When communicating advice or instructions, it's essential to consider this aversion to loss and potentially reframe or rephrase suggestions accordingly.

Hyerpbolic discounting This involves valuing immediate investments and returns more than those in the future. This bias influences decisions, making people favour immediate actions and rewards over delayed ones, even if the long-term benefits are significant.

In your communication, it's beneficial to minimize the perception of immediate investment and enhance the perception of immediate returns. This makes your message more persuasive, considering that people often have a return on investment mindset influenced by biases like sunk cost fallacy, loss aversion, endowment effect, and hyperbolic discounting.

13 Global governance

13.1 Study guide

- You should clearly understand the concepts discussed in the module and be able to recognize examples.
- Important concepts: principle of sustainable development, intergenerational equity, principle of sustainable use, intragenerational equity, integration principle, national sovereignty, principle of preventive action, precautionary principle, polluter pays principle, common but differentiated responsibility, risk assessment, environmental justice (with all its elements), collective action problem, multilateral negotiations, polycentric governance

You don't need to read the court rulings on Bayer and chlorothalonil in chapter 3.3. The text 'Legal aspects of the choice of environmental policy instruments from the point of view of Belgian, European and international law' in chapter 4.1 does not have to be studied. You don't need to memorize the conventions' names or years in chapter 5.2.

13.2 Jurisdiction

13.2.1 Legal principles of sustainable development

This part of the course introduces the principles of sustainable development based on the 1992 Rio Declaration and its updates.

13.2.1.1 The principle of sustainable development

Principle three of the Rio Declaration states:

> The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.

This principle originated from the World commission on Environment and Development, better known as the Brundtland Commission. It came as a response to address the accelerating deterioration of the environment. Because of the work done by this commission we have a definition of 'sustainable development'. It takes the form of a three-tier concept encompassing ecological, social and economic development.

In international law, sustainable development is mainly broken down into four parts:

- The principle of intergenerational equity, which amounts to the need to preserve resources for future generations.
- The principle of sustainable use refers to a more immediate concern to use resources wisely.
- Intra-generational equity implies the balanced use of the world's resources by the various parts of the world
- The principle of integration implies that environmental considerations are taken into account in economic and development objectives.

13.2.1.2 National sovereignty over natural resources

Principle two of the Rio Declaration reads as follows:

> States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction

This essentially means that the international laws about sustainability have State sovereignty over its own resources as a cornerstone. However, this does not mean that States can do whatever they like, they can not inflict damage to the territory of other States for example. Environmental challenge the classic theory of international law regarding territory and State sovereignty. This is why there is a relatively new part of a States sovereignty: the protection of the global commons. This was added to the traditional three regimes vis-à-vis jurisdiction:

- The majority of the Earth is subject to territorial sovereignty.
- Res nullius are those parts of the Earth which are capable of lawful national appropriation/sovereignty, but are as yet unclaimed.
- Res communis are shared by all nations and cannot be placed under State sovereignty

Especially the distinction between global commons and res communis is relevant. The largest challenge is to find a way for parties to adjudicate regulatory power over the global commons. There are some concerns about:

- Alleviates veto concerns: one can not assume that global consensus will be found over issues concerning global commons. If this was the case, every State would effectively hold veto power over the management of these.
- Unbridled unilateralism or even selective multilateralism indeed would risk rewarding coercion.

13.2.1.3 The principle of preventive action and the precautionary principle

Principle two seen in paragraph 13.2.1.2 in combination with principle 15 of the Rio Declaration define the prevention principle:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation

This principle obliges authorities to take action at the earliest possible stage to prevent known risks from being realized. There however is not an undisputed definition of the precautionary principle. Generally though, it is defined in a more negative sense: States must not defer regulatory action even if there is no conclusive scientific proof between a given (in)action and damage to the human health or environment.

As for the content of the principles, they can be distinguished in terms of the types of risks one has to manage. Preventative deals with known risk and precautionary deals with uncertain risks. The former is also part of international law while the latter is again disputed.

13.2.1.4 The polluter pays principle

Principle 16 of the Rio Declaration states:

> National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment

The polluter pays principle requires all environmental costs to be internalized by the companies which cause them. Theoretically full introduction of this would result in this being a cost on a company's account. In reality the principle is faced with a lot of many challenges. For example, it is not easy to calculate the economic value of pollution. When this is feasible though, one still needs to find the polluter and be able to hold them accountable. The biggest obstacle by far is the unwillingness of politicians to actually implement this into the law.

13.2.1.5 Common but differentiated responsibility

Principle seven of the Rio Declaration states:

> States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command

This principle is one of common sense, although it can be quite sensitive at times. Because of the wording used to make this principles, countries like China and India think they have the right to postpone their climate efforts.

13.2.2 Law enables and disables

The law can be used as a shield and as a sword. For example when someone steals your bike, you can use the receipt you got as a sword to prove that the bike is yours. On the other hand, if you are falsely accused of stealing that bike, you can use the same receipt as a shield to protect yourself and your bike.

These concepts also apply to international law, however it is much more difficult to use the law as a sword because of the vague wording used to make these laws. In practise they are good shields for States to protect themselves but bad swords for parties who want to fight lacklustre attempts from States to follow these laws.

13.3 Law and science

13.3.1 Risk regulation: an introduction

13.3.1.1 Benzene and the risk assessment revolution

Benzene is an influential court case handled by the US Supreme Court. It is widely seen as having introduced risk assessment as the default standard for risk analysis by US regulators as it led to the commissioning of the National Research Council (NRC).

The resulting risk assessment guidelines in the US Government hold 10 recommendations. It acknowledges that assessment can not be made completely free of policy considerations, but emphasized that steps should be taken to manage and assess risks. The ultimate aim of these guidelines in dealing with risk is 'to evaluate trade-offs between health consequences and other effects of specific regulatory actions.'

13.3.1.2 Risk assessment in the EU

The EU has only recently started to consider the conceptual approach to risk analysis as carried out at the EU level. Three main developments have led to the current approach to risk management.

National risk management failures and their backlash at the EU level

Generally, regulatory failures often drive regulatory developments. Precious little regulatory law is inspired by a purely academic risk analysis exercise. Quite literally, from the ashes of disaster grow the roses (whether or not thorny) of regulatory success.

Governance and the impact on regulation

The European Commission has highlighted the increasing reliance, in the development of EU regulatory law, on expert advice, and the consequential need on public trust in that advice.

The impact of the precautionary principle

In 2000 the EU adopted a Communication on the precautionary principle which is arguably the highest-profile attempt to translate the principle into guidelines. The Commission insists in this document that the precautionary principle in its European context is a justified part of risk management.

The EU and its Member States view risk analysis as a linear process, in which the various steps of a risk analysis process (risk identification, risk assessment, risk management, and risk communication), are neatly divided. Importantly, the EU assigns the responsibility and the main lead in each of these steps to different professional groupings. Whilst the steps of risk identification and certainly that of risk assessment are a responsibility of scientists, the step of risk management is very firmly seen as a political step, in which elected politicians on both the national scene and the European scene, take the lead. This preponderant role of politicians in risk management, makes the process prone, so its critics say, to being susceptible to scaremongering, and to recourse to the precautionary principle.

13.3.1.3 The law is in awe of science

Many people believe that the law should be based on objective scientific facts. This has been the standard for global law when it comes to regulating risks, usually taking the form of risk analysis. We distinguish four steps during this process:

Risk Identification The identification of a potential risk: 'I wonder what the impact would be if ...'

Risk Assessment This is the objective scientific step where we assess what happens, what impact there could be, what will it cost to solve this problem...

Risk Management What should we do about the risk that we have just explored in our scientific arguments? This step is also very different depending on which part of the world you are in, even though it is based on the same objective facts established in the previous step.

Risk Communication Communicate the risk management measure that you have taken.

13.4 Regulation vs. liability

13.4.1 Types of regulation

As seen in the study guide (section 13.1), this is irrelevant for the exam.

13.4.2 How does a regulator regulate

To give an illustration from the real world, we look at **Article 191** of the Treaty on the Functioning of the European Union. This article instructs the European Commission (EC) on how to create policy for environmental protection. **The EC essentially has to take into account a 'high level' of environmental protection**, because the article functions as the starting point for environmental policy. Even though this sounds good, the article immediately goes on to nuance its standpoint.

For example, they need to take into account **'available scientific and technical data'** to make a law, but in a lot of cases this is not present: for example, the effect of asbestos on people was not known when it was introduced. Furthermore, the EC must take into account **'environmental conditions in the various regions of the Union'**, complicating matters even more. Thirdly, the EC as to take **'the potential benefits and costs of action or lack of action'** into account. This is not always easy because what is protecting the environment actually worth to us? Lastly, the EC needs to take into account **'the economic and social development of the union as a whole and the balanced development of its regions'**.

13.5 Environmental justice

13.5.1 A history of environmental governance

Initially, environmental policy started at the national level of a State. Specifically in the US, the triggering event was the discovery of the hazards of DDT. Somewhere along the line, countries realized that pollution doesn't stop at the border. Since globalization has grown fast, countries increasingly consume products that were produced elsewhere. This means that people's consumption can cause environmental harm outside of their country. This external impact often is called an **external footprint**.

For example, an external footprint is that 75% of greenhouse gas emissions costs by producing the clothes, footwear and household textiles that we consume in the European Union, actually occurred outside of Europe. Another example is that EU consumption causes 10% of global deforestation, almost all of which takes place outside the EU. Finally, EU food imports causes external land and water use impacts. These examples demonstrate how countries and the European Union bear responsibility for environmental problems outside their borders. **Those environmental problems can only be addressed through collaboration with other countries**.

Against a backdrop of growing globalization and the transboundary nature of environmental pollution, many of the problems that we face are so-called **collective action problems**. They are characterized by a situation in which multiple individuals or countries would benefit from a certain action. But that action comes at a cost. Which is why individuals are unlikely to pay that cost if the others are not doing likewise. Costly decisions are thus made individually, but the benefits are for everyone. In such a situation, voluntary change seems unlikely. Some authoritative agreement or organization seems required to make everyone contribute to addressing the problem.

In order to solve these problems together, a number of pioneering countries set the international political agenda, which led to the first global environmental conference. This gave rise to the United Nations Environment Program (UNEP) which monitors the global environment. Later, the Brundtland report discussed in paragraph 13.2.1.1 came out and gave rise to the Rio Declaration.

Over the next 10 to 20 years, updates were made to declarations and proposals such as the Rio Declaration. This brought the issues at hand back into focus for political leaders. Finally, this led to the creation of the sustainable development goals or SDGs.

13.5.2 Environmental justice

In 2019, *the French* held the yellow vest protests against rising taxes for fossil fuels. This clearly showed that environmental policy should take social aspects into account. It is important to think about the effects of a policy change so that it does not disproportionally hit a certain group of the society. The film 'Erin Brokovich' also illustrated these principals.

To summarise, **environmental justice** is a **multifaceted concept that varies depending on issue, context and analysts**. Although the two examples are local ones, environmental justice **plays an important role from the local to the global level**. Essentially, we have to **ensure equity between privileged and unprivileged groups and individuals**.

13.5.4 Elements of environmental justice

There are three main aspects or elements of environmental justice as depicted in figure 53.

Distribution How are costs and benefits allocated among actors? This is already included in the Rio Declaration discussed in paragraph 13.2.1.5.

Recognition Are differences respected? Do certain actors dominate?

Procedure How are decisions made and by whom? This is about an inclusive process and enabling every actor to participate.

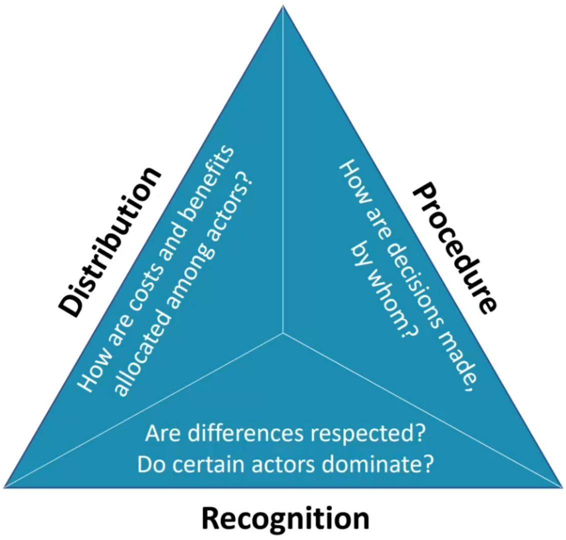


Figure 53: Elements of environmental justice

There are also additional aspects to think about:

Compensatory justice Do countries who suffer from climate change receive a compensation from countries who contributed a lot to it?

Intergenerational justice Should we act now to solve climate problems or leave them to future generations to deal with?

Interspecies justice This is the balance between humans and nature.

13.6 Multilateral negotiations

13.6.1 Multilateral environmental negotiations

Getting multiple parties to agree about environmental negotiations is highly complex. This is due to a number of challenges:

- The great number of participants, on climate change conventions there are about 195 countries present
- International negotiations are characterized by consensus decision-making
- Diverging interests of countries make it difficult to find common ground
- Diverging perceptions
- Issue complexity, such as biodiversity, chemicals and, of course, climate change
- There is often not a single solution to a problem. (complexity + uncertainty)
- The North-South divide regarding development of countries of the world plays a big role as well
- Politicization of climate change and environmental policy
- Inserting strong compliance and enforcement mechanisms in international treaties is very difficult because countries want to safeguard their serenity
- Lack of enforcement

Ultimately we try to find a zone of agreement between all the negotiating parties.

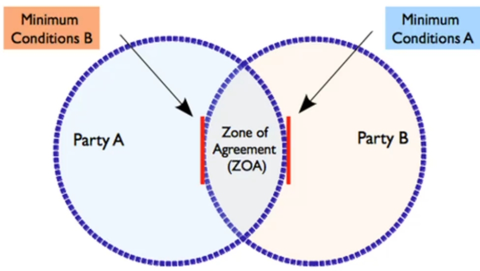


Figure 54: Zone of agreement

Due to all the difficulties, a lot of coalitions have formed amongst the smaller delegations which are roughly depicted in figure 55.

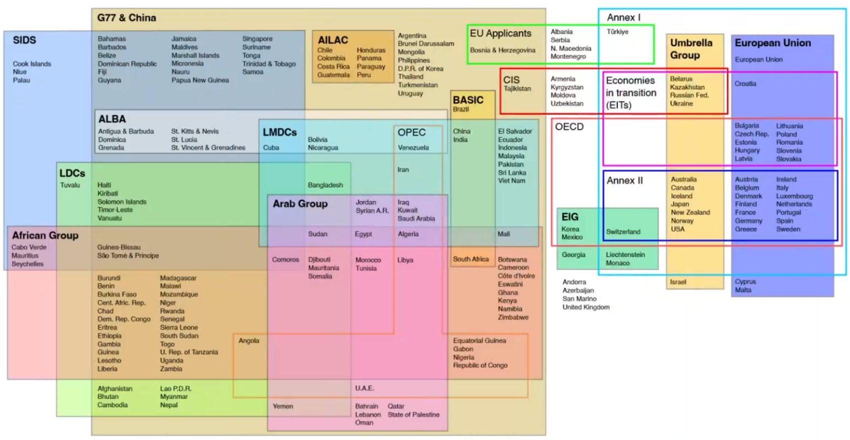


Figure 55: The coalitions

13.6.2 Poly-centric governance

Poly-centric governance is a complementary perspective to multilateral negotiations. Here, multiple governing authorities adopt their own measures addressing a certain problem. Many environmental problems can be adopted to achieve local benefits in addition to global ones such as solving local air pollution. Each authority adopts measures independently under this system and is not forced to do so. States can still influence each other though by, for example, learning from each other.

Is poly-centric governance an effective way to deal with these problems? In some cases, this can certainly be done; but sometimes it is just not possible, so we revert to multilateral negotiations. Usually we fail because of the shortcomings in poly-centric governance:

Leakage This is when an activity that would occur in one location is simply shifted to another location, the overall problem is thus not solved.

Inconsistent policies When policies differ, the incentive to develop a technology and innovation may not be high enough given the size of the jurisdiction in which it could be solved.

Free riding Some actors can benefit from a policy adopted by others without contributing to addressing the problem.