Environmental Analysis and Ecology
HSLU, Semester 4

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Contents

Week 1

1 TODO

Carrying capacity in general systems:
The maximum level of output or performance that a system can sustain over time without experiencing degradation or failure.

Sensitivity analysis: sensitivity of a single parameter and how much it impacts

Scenario analysis: optimization of multiple parameters to minimize the resultant impact

Carrying capacity in population:
Maximum population size of a species that an environment can sustain indefinitely, given the available resources and environmental conditions.

Week 2

2 Systems

2.1 Characteristics

- Input and Output
- Set of components
- Rules and relationships between components
- System's boundaries

2.2 System's loops

2.2.1 Feedback loops

Feedback loops are the system's response to changes
Two types of loops:

- Positive feedback loops (Reinforcing):
  Causes systems to change further in same direction
- Negative feedback loops (Balancing):
  Causes systems to change in opposite direction from which it is moving

2.2.2 System's responses

Time delays Complex systems often show time delays between input of a feedback stimulus and the response to it **(oscillating graph)**
Ex: Population growth or global climate change

Synergistic interaction System effects can be amplified through synergistic interaction

2.3 Casual loop diagram (CLDs)

CLDs are maps showing casual links with arrows from a cause to an effect and it allows the identification of polarity of feedback loops (positive or negative)

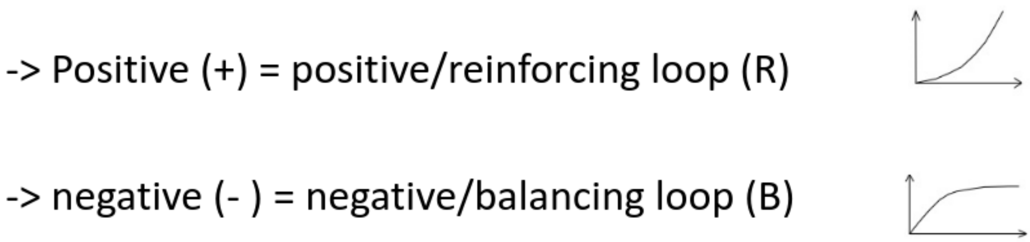


Figure 1: Reference Behavior Pattern

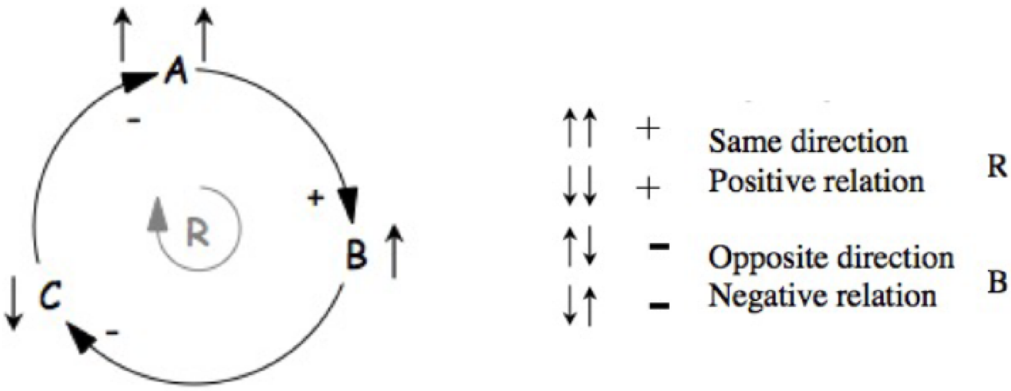


Figure 2: RBP Example

2.4 Reference Behavior Pattern (RBP)

Example If A increases, B will increase (↑↑)

- Arrows show same direction → assign (-)
- Variables can also be decreasing in the same direction (↓↓) → also assign (-)

If B increases, C decreases (↑↓)

- Arrows show opposite directions → assign (-)

If C decreases, A increases (↓↑)

- Arrows show opposite directions → assign (-)

So:
A↑ → B↑ → C↓ → A↑↑ (Reinforcing Loop)
A↓ → B↓ → C↑ → A↓↓ (Reinforcing Loop)

3 Ecosystems

3.1 Energy flow in ecosystems

Robustness in ecosystems is the capacity of an ecosystem to withstand disturbances (e.g., drought, fire, pollution) while maintaining its structure and key functions.

It is important because it helps prevent collapse into degraded states and preserves ecosystem services like nutrient cycling, productivity, and biodiversity support.

3.2 Cycles in the biosphere

3.2.1 Nutrient cycle

TODO

3.2.2 Hydrologic cycle

TODO

3.2.3 Nitrogen cycle

- Major reservoir for the nitrogen is the atmosphere (78%)
- Nitrogen cannot be directly absorbed and used as a nutrient by plants or animals

Human alteration

- Humans add large amounts of nitric oxide (NO) into the atmosphere by burning any fuel at high temperatures (e.g. car, jet engines) → acid rain
- Nitrous oxide (N_2O) in atmosphere through commercial inorganic fertilizers → N_2O is a GHG and depletes stratospheric ozone
- Large quantities of nitrogen stored in soils and plants through destruction of forests, grasslands, and wetlands
- Humans alter nitrogen cycle in aquatic ecosystems through agricultural runoff and discharges from municipal sewage systems

3.2.4 Phosphorus cycle

- Phosphorus circulates in the soil mainly, also through water, the earth's crust, and living organisms
- As water runs over exposed phosphorus-containing rocks and dissolves phosphate
- Phosphate is mainly absorbed by plants roots

Human alteration

- Removal of large amounts of phosphate from the earth to make fertilizers
- Soil from fertilized crop fields carries large quantities of phosphates into streams, lakes and the ocean, where it stimulates the growth of algae
- Phosphate runoff from sewage water and mining waste

3.2.5 Sulphur cycle

- Most of the earths sulphur is stored underground in rocks and minerals, including sulphate salts buried under ocean sediments
- Sulphur also enters the atmosphere from several natural sources (e.g. active volcanoes, organic matter, which is broken down by anaerobic decomposers) → Deposited as acid rain

Human alteration

- Release of large amounts of sulphur dioxide into the atmosphere → Acid rain
  - Burning of coal and oil to produce electric power
  - Refining of sulphur-containing fossil fuels to make gasoline and heating oil
  - Conversion (smelting) sulphur-containing metallic mineral ores into free metals such as copper, lead, and zinc

3.2.6 Carbon cycle

- Carbon cycle is based on carbon dioxide (CO_2)
- 0.038% of the atmosphere consists of CO_2
- CO_2 is a key component of natures thermostat:
  - If too much CO_2 is removed from the atmosphere → atmosphere gets cooler
  - If too much CO_2 is added to the atmosphere → atmosphere gets warmer
- Plants and animals exchange CO_2 with the atmosphere through photosynthesis and respiration
- Carbon stored more permanently in plants returns to atmosphere as CO_2 through decomposition

- Oceans absorb and emit carbon to the atmosphere, and some of this carbon ends up accumulated at the bottom of the ocean
- Humans heavily contribute carbon to the atmosphere:
  - Extraction of fossil fuels → CO_2 emissions due to combustion

Week 3

4 Biodiversity

4.1 Definition

Biodiversity is the variety of earths species, the genes they contain, the ecosystems in which they live and the ecosystem processes (energy flow and nutrient cycling).

TODO

5 Species diversity

5.1 Population dynamics

5.1.1 Population

Group of individuals of the same species that live in the same place at the same time

5.1.2 Population factors

- Distribution
- Size
- Age structure
- Density

5.1.3 Population dynamics

Study of how population characteristics change in response to changes in environmental conditions.

Four factors that determine population size:

- Births
- Deaths
- Immigration
- Emigration

Population change is defined as:

$$\boxed{\text{population change} = (\text{births} + \text{immigration}) - (\text{deaths} + \text{emigration})}$$

Age structure can have a strong effect on how rapidly a population size increases or decreases:

- Pre-reproductive age (not mature enough to reproduce)
- Reproductive stage (capable of reproduction)
- Post-reproductive stage (too old to reproduce)

5.1.4 Growth functions

Species vary in their capacity for population growth under ideal conditions

5.1.5 Intrinsic rate of increase

Rate at which the population of a species would grow if it had unlimited resources.

Populations with high intrinsic rate of growth typically reproduce early in life, have short generation times (time between successive generations), can reproduce many times, and have many offspring each time they reproduce.

5.1.6 Carrying capacity

Intrinsic rate of increase and environmental resistance = carrying capacity.

Definition:
Maximum population of a given species that a particular habitat/area can sustain indefinitely without being degraded

- Carrying capacity of an area is not fixed
- A population with few (or no) limitations can grow exponentially
- Environmental resistance slows down growth rate as population size gets closer to carrying capacity:
  → logistic growth curve or S-shaped growth curve

5.2 Human influence

Extinction rate caused by human influence will increase to 10,000 times the background extinction within this century.

Annual extinction rate of ca. 1% per year (currently between 0.01 - 0.1%)

New species eventually evolve to take the places of the lost one.

Week 4

6 Stock and flow diagrams (SFD)

6.1 Translating CLDs into SFDs

- CLDs represent conceptual models, which depict causal mechanisms based on underlying reference behaviour patterns (RBPs)
- First step in computational modelling of CLDs is the translation of CLDs into SFDs

6.2 Stock and flow diagrams (SFDs)

- SFDs provide a richer visual language than CLDs
- Six basic elements exist in SFDs: **Stocks, Flows, Converters, Connectors, Sources, and Sinks**

6.3 Components of SFDs

6.3.1 Stocks

A stock is a "part of a system whose value at any given instant in time depends on the systems past behavior".

A stock is defided as:

$$\boxed{\text{Stock} = \int_{t_0}^{t_1} (\text{inflow - outflow})\, dt + \text{value right before starting}}$$

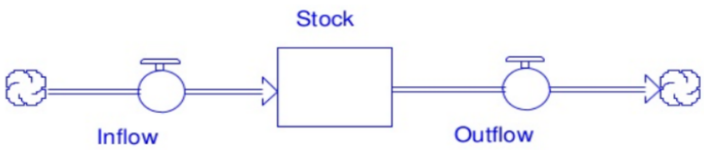
- Stocks represent anything that accumulates (normally in both directions)
- **Stocks are only affected by inflows and outflows**
- Stocks are normally tangible, countable and physical

- But can also be non-physical (e.g. level of fear, aggression)
- Non-tangible stocks require special attention, since differences in numerical translation might cause different system behaviours

- Stocks are usually presented by nouns

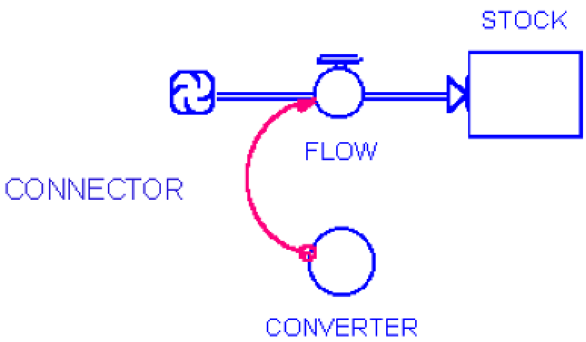
6.3.2 Flows

- Represent activities that lead to inflows and outflows to stocks (e.g. births, migration)
- Inflows cause the stock to increase
- Outflows decrease the stock
- Flows are usually presented by verbs or nouns describing an action



6.3.3 Converter

- Contain equations that generate an output value during each time interval of a simulation (e.g. birth rate, migration rate)
- Can also be used for storing constant values (e.g. initial population size)

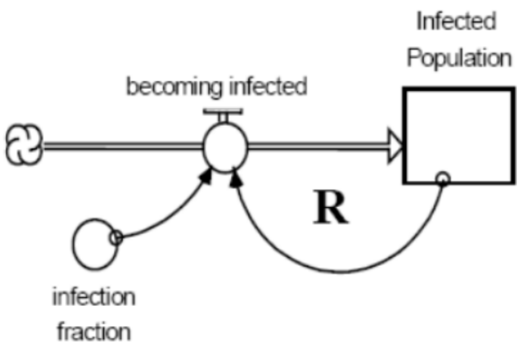


6.3.4 Connectors

- Transmit information to regulate flows
- Connectors can connect into flows or converters but never into stocks

6.3.5 Source and Sink

- Stocks that lie outside the system boundary
- Sources and sinks are shown as clouds in the diagram.
- Are used to show that a certain stock inflow is coming from another source (e.g. migration)
- Or that an outflow ends up in another stock outside the system (e.g. emigration)



Week 5

7 Climate

7.1 Weather vs. climate

Weather:

- Weather is a local, short term phenomenon
- Weather is mainly expressed by temperature, humidity, precipitation, wind speed, cloud cover
- Measured over hours or days

Climate:

- Areas general pattern of atmospheric or weather conditions
- Measured over long periods of time (ranging from decades to thousands of years)

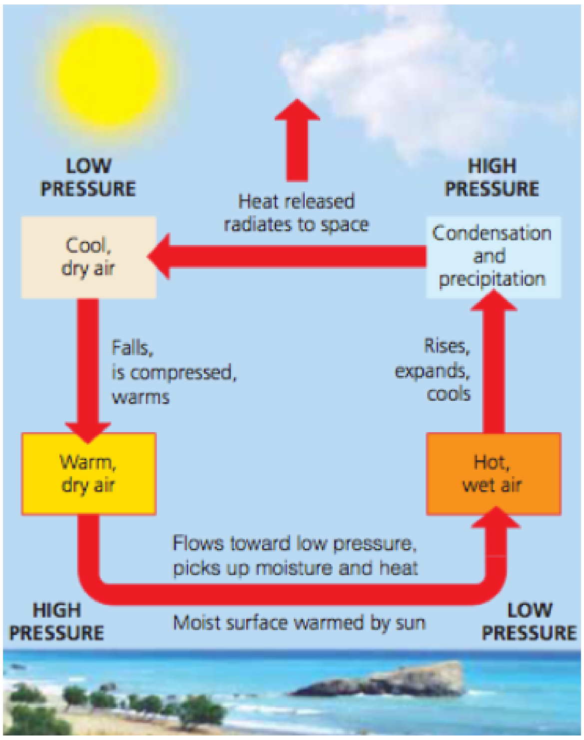
7.2 Climate factors

7.2.1 Climate zones

- Important component of earth's natural capital
- Climate variations caused by patterns of global air circulation and ocean currents

7.2.2 Factors of air circulation in lower atmosphere

- Uneven heating of earth's surface → Air is heated more at the equator
- Rotation of the earth around its axis:
  - Heated air masses rise above equator and move north and south
  - Atmosphere divided in cells, distinguished by direction of air movement
  - Differing directions of air movement are called **prevailing winds** (major surface winds that blow almost continuously and distribute air, heat, moisture and dust)
  - Prevailing winds also produce mass movements of surface water (currents)
- Properties of air, water and land:
  - Heat from the sun evaporates ocean water and transfers heat from the oceans to the atmosphere, especially near the equator
  - Evaporation of water creates cells (low and high pressure) which circulate air, heat, and moisture



7.2.3 Ocean conveyer belt (thermohaline circulation)

- Heat is also distributed when ocean water mixes vertically in shallow and deep ocean currents
- Result of differences in the seawater density
- Colder seawater (higher density) sinks and flows beneath warmer and less dense seawater
- Connected loop of deep and shallow ocean currents

- Acts like giant conveyer belt that moves heat to and from the deep sea
- Transfers warm and cold water between tropics and poles

7.2.4 Link between ocean and atmosphere

- Ocean currents are affected by winds in the atmosphere
- Heat from the ocean affects atmospheric circulation

7.2.5 Earth's surface features

- Heat is absorbed and released more slowly by water than by land:
  → Difference creates land and sea breezes → oceans and large lakes moderate weather and climates of nearby lands
- Topographic features of earths surface can create local and regional weather and climatic conditions that differ from the general climate of a region (e.g. mountains)

7.2.6 Greenhouse effect warms lower atmosphere

- Greenhouse gases allow visible light (and some infrared radiation and UV radiation) from the sun to pass through the atmosphere
- Earths surface absorbs much of this solar energy and transforms it to heat, which then rises into the lower atmosphere
- Some of this heat escapes into space, but some is absorbed by molecules of greenhouse gases → Warms the lower atmosphere and the earths surface (greenhouse effect)

8 Climate change - natural cycles

8.1 Characteristics of climate change

8.1.1 Natural variations

- Changes of earths climate are neither new nor unusual
- Atmosphere has experienced prolonged periods of global cooling and global warming
- Alternating cycles of cooling and warming are called glacial and interglacial periods

9 Natural forces

9.1 Milankovitch cycle

9.1.1 Variations

Earth's orbit
Earths orbit changes from being nearly circular to slightly elliptical (termed eccentricity)

→ Cycle has a period of around 100.000 years

→ The more elliptic the orbit becomes, the less time the earth spends near the sun

→ Less solar energy leads to cooling effect

Angle of tilt
Angle of tilt of the earths axis changes from 22,1° (22,5) to 24,5° (term obliquity)

→ Cycle has a period of 41.000 years

→ Land mass of the northern hemisphere face more/less towards the sun

→ Leads to cooling/warming effects

Direction of tilt
Direction of tilt of the axis changes (termed precession)

→ Cycle has a period of 26.000 years

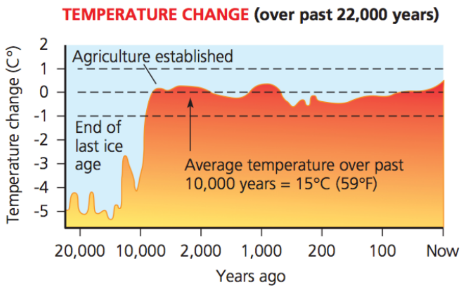
→ Causes winters and summers to be warmer or colder depending on the amount of land surface being more or less exposed to the sun

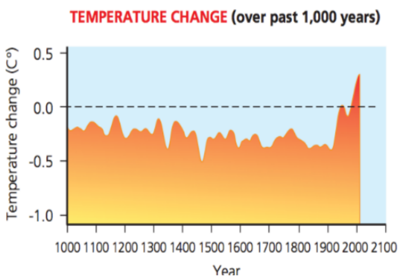
10 Anthropogenic climate change

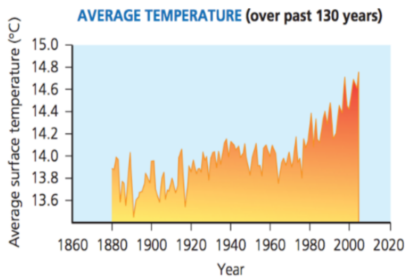
10.1 Global warming

10.1.1 Today's climate

- For ca. 10,000 years earths climate is in an interglacial period
- It is characterized by a fairly stable climate and a fairly steady average global surface temperature
→ Allows agriculture → triggered population growth
- Average temperature of the atmosphere has remained fairly stable for the last 1,000 years
- Temperature started rising during last century







The 0 temperature change line was set based of the average temperature right after the beginning of the industrial revolution.

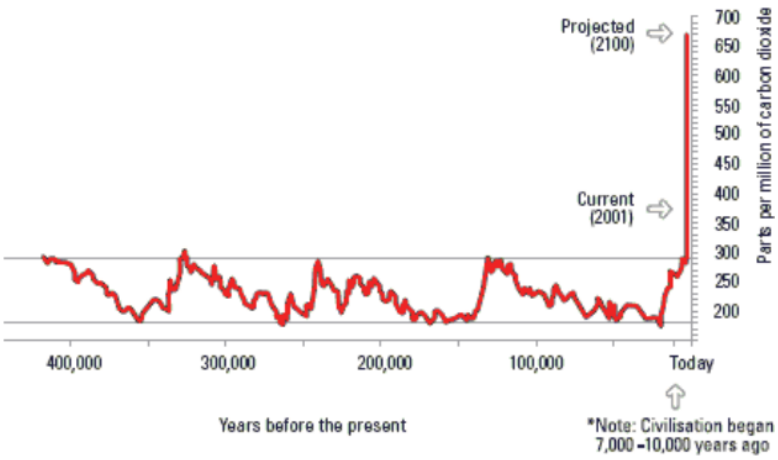
10.2 Greenhouse effect

- Life depends on natural greenhouse effect → Without natural greenhouse effect no life would exist and earth would be too cold
- Since Industrial Revolution significant increase in CO_2, CH_4, and N_2O concentration in lower atmosphere
→ Increases is mainly due to agriculture, deforestation and burning of fossil fuels
- Measurements of CO_2 and CH_4 in glacial ice cores indicate high correlation between concentration level and average global temperature

10.3 Greenhouse gas emission

- CO_2 level has risen from 280 ppm (around 275 years ago) to 399 ppm in 2014
- If CO_2 emissions continue to increase at current rate of about 3.3% a year
  → Levels will rise to 560 ppm by 2050 and to 1,390 ppm by 2100
  → Significant changes in earths climate
  → Major ecological and economic disruptions
- CO_2 levels should be prevented from exceeding 450 ppm
→ Estimated tipping point that sets into motion large-scale climate changes
- Ideally: reduction of CO_2 to 350 ppm (pre-industrial level)
→ Stabilizing earths climate

10.3.1 CO_2 emission over time



Due to the periodic changes in the Earth's orbit, from elliptical to circular and vice versa, the more elliptical the orbit is, the farther the Earth is from the Sun, the fewer plants there are, and the less CO_2 is stored.

Nowadays, the amount of CO_2 in the atmosphere is higher than ever due to industrialization.

10.3.2 Global Warming Potential (GWP)

- Describes potential impact of each greenhouse gas (GHG)
- Some GHGs are more effective at warming the atmosphere than others
- Most important characteristics of a GHG in terms of climate impact are:
  → Energy absorption potential (preventing energy from escaping to space)
  → Residence time of gas in atmosphere
- GWP measures total energy that gas absorbs over 100 years, compared to CO_2

Greenhouse Gase	Chemical formula	Global Waeming 20 years	Potential (Time horizon) 100 years
Carbon dioxide	CO_2	1	1
Methane	CH_4	42-70	16-26
Nitrous oxide	N_2O	280 ⟷	310

10.3.3 Methane CH_4

- 60% of methane emissions occurred during last 275 years
- Extraction of fossil fuels, creating landfills, raising cattle and sheep
- CH_4 emissions have levelled off since 1990
- Are expected to rise again → melting of permafrost in the arctic tundra
- GWP: 16-26 times greater than CO_2

10.3.4 Nitrodus oxide N_2O

- Nitrous oxide levels have risen ca. 20% during last 275 years
- Increased use of nitrogen fertilizers
- GWP: 280 times greater than CO_2

10.4 Effects of a warmer atmosphere

10.4.1 Extreme weather events

- Increased incidence of extreme weather events such as heat waves, droughts, flooding
- Controversy over the question if global warming also increases frequency and intensity of tropical storms and hurricanes
- Hurricane Katrina caused loss of over 320 million big trees
  → dead and damaged trees emitted CO_2 equal to the total amount that all forest trees in the U.S. absorb in one year

10.4.2 Effects on biodiversity

- ca. 30% of the land-based plant and animal species could disappear if average global temperature change exceeds 1.5-2.5 °C
- Percentage could grow to 7% if temperature change exceeds 3.5 °C
- Hardest hit will be plant and animal species in colder climates
- Global warming could also disrupt biological clocks of birds, whales, and other migratory species
- Ecosystems will suffer disruption (e.g. coral reefs, polar seas) → species extinction

10.4.3 Effects on humans

Nutrition

- Agricultural productivity may increase in some areas and decrease in others
- Crop productivity is projected to increase slightly at middle to high latitudes
- Agricultural productivity will decrease in tropical and subtropical regions
- Flooding of rivers and droughts reduces crop production
- IPCC warns that ca. 200-600 million people could face malnutrition/starvation from climate change effects

Health

- Fewer people will die from cold weather, but heat-related deaths will increase
- Better living conditions for rapidly multiplying insects, microbes, toxic moulds
- Infectious diseases (e.g. dengue fever, yellow fever, malaria) are likely to expand their ranges
- Higher atmospheric temperatures also increases some forms of air pollution
  → Speeds up chemical reactions, which causes photochemical smog in urban areas
- WHO estimates that currently each year, climate change contributes to premature deaths of more than 150'000 people

10.4.4 Reduction of GHG emissions

4 steps for CO_2 reduction

1. Change the type of fuel (conversion of primary source)
2. Maximize the efficiency of conversion of the fuels
3. Increase the energy efficiency of the device itself
4. Change the behavior of the humans

Major GHG reduction strategies

- Improving energy efficiency to reduce fossil fuel use
- Shift from non-renewable (carbon-based) fuels to (carbon-free) renewable energy sources
- Stop cutting down tropical forests

- Effectiveness of these strategies would be enhanced by reducing population

  → Decreasing number of CO_2 emitters

  → Reducing poverty

  → Decreasing need to clear more land for crops and fuel wood

Geo-engineering

- Capturing and storage of CO_2 (and keep burning fossil fuels)
- Injection of sulphate particles into stratosphere → reflection of incoming sunlight
- Space sunshades

Week 6

11 Analytical tools for energy and environmental systems

11.1 Characteristics of energy systems

11.1.1 Relationship between energy use and wealth

- Most used measure for wealth = GDP
- GDP = sum of monetary value of all goods and services produced in a country/year
- GDP value may be adjusted to reflect purchasing power parity (PPP) → A dollar equivalent earned in one country may not buy as much as in another country
- GDP per capita is correlated with energy use per capita → GDP rises with energy use (per capita)

11.1.2 Quality criteria of energy resources

- Must be reliable and deliver the service that the consumer expects
- Must be available in the quantity desired and when the consumer wishes to consume it
- Resource must be available at a price that is economically affordable
- If quality criteria are not met, direct consequences are experienced

11.1.3 Long term criterion

- Another criterion for energy resource is environmental sustainability
- Problem: consumers of energy resources do not experience direct consequences if this criterion is not met

11.2 Energy systems categories

- Physical goals
- Financial goals
- Environmental goals

11.2.1 Physical goals

- Physical requirements that make it possible for the system to operate
- All systems require primary energy resources
- Any type of energy system must function efficiently, reliably, and safely

11.2.2 Financial goals

- For small-scale, privately held systems goal might be to reduce energy
- For commercial energy systems the goal is normally profit maximisation (returning profits to shareholders)

11.2.3 Environmental goals

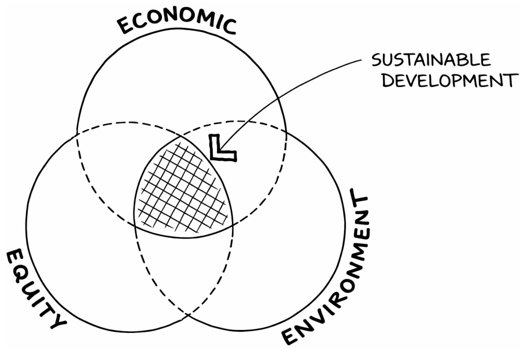
- Reduction of GHG emissions
- Reduction of air pollutants → increase of air quality
- Minimization of physical effects from extracting resources
- Minimization of impacts on physical surroundings, such as noise or vibrations
- Reduction of (thermal) pollution of water
- Avoidance of disruption of natural habitats

11.3 Objectives

- Use of existing technology options in a different way
- Conserving energy by replacing end-use technology → Primary energy source remains the same, but new technology is introduced to use energy resource more efficiently
- Conserving energy by replacing conversion technology → Same primary source of energy (e.g., fossil fuels), but conserve energy by replacing the energy conversion device with a more efficient model
- Replacing existing energy sources with alternatives

11.3.1 Overall sustainability objectives (Sustainable development)

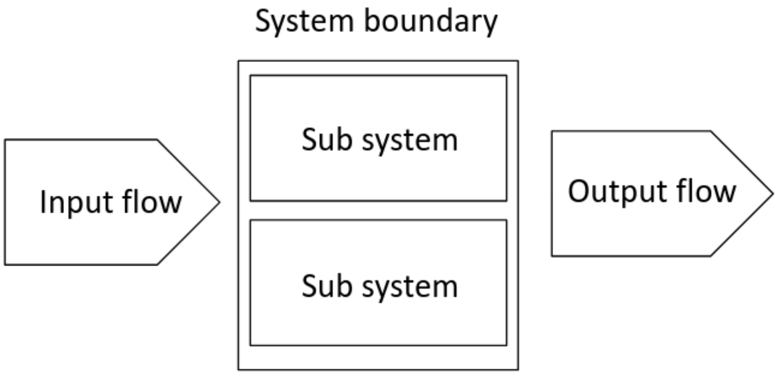
- Environmental sustainability: protection of the environment
- Social/cultural sustainability: increasing equity (decreasing poverty)
- Economic sustainability: responsible economic development



11.4 Definition of energy systems

- "A system is a set of components that function and interact in some regular way"
- Group of interacting components that work together to achieve some common purpose
- Each system has a boundary: physical or conceptual → Entities or objects that are not part of system lie outside the boundary
- Area outside the boundary is called the environment
- Energy systems have input and output flow between the system and its environment
- Inputs and outputs may be physical (e.g. raw materials) or virtual (e.g. information, data)
- Systems can consist of subsystem (e.g. electricity grid)
- Defining boundaries, input and output flows and subsystems is essential

11.4.1 Energy systems diagram



where:

- **System boundary**: defines what is included in the analysis and what is outside the system to study the relevant components and interactions
- **Input flow**: represents the resources entering the system, such as energy, materials, or information
- **Sub system**: a smaller internal part of the main system with a specific function
- **Output flow**: represents what leaves the system, such as useful energy, waste, emissions, or information

11.5 Energy return on investment (EROI)

- End-use energy derived from a particular resource needs to justify energy expended upstream in its extraction, conversion and delivery:
  - **Upstream: everything before the operational phase**
  - **Downstream: energy or money used to dismantle the energy system or to end it**
- EROI = energy delivered at the end of the life cycle / energy used in earlier stages
- EROI presents the amount of energy returned from the use of an energy source after expending energy on manufacture, installation etc.

11.6 Energy payback time (EPBT)

- EPBT expresses the years it takes for a certain technology to produce as much net energy as it takes to manufacture and dispose the technology
- Used as a measure of energy efficiency from an investment perspective
- EPBT must be much less than lifetime of technology

$$\text{EPBT} = \frac{\text{Cumulative energy demand}}{\text{Yearly net energy generated}}$$

$$\text{EPBT} = \frac{E_{\text{Materials}} + E_{\text{Manufactoring}} + E_{\text{Installation}} + E_{\text{Disposal recycling}}}{\text{Energy generated} - E_{\text{O\&M}}}$$

where $E_{\text{O\&M}}$ is the energy used in operations and maintenance, which is subtracted from the energy generated

11.7 Kaya equation (Kaya identity)

- System approach for analysing factors that contribute to overall CO_2 emissions (country or global base)
- Approach includes population, level of economic activity, level of energy consumption, and carbon intensity

$$CO_2 = P \cdot \frac{GDP}{P} \cdot \frac{E}{GDP} \cdot \frac{CO_2}{E}$$

where:

- P: population (of a specific country)
- GDP/P: production per capita (to evaluate how wealthy the population is)
- E/GDP: energy intensity per unit of GDP (energy intensity of the population's economy / how much energy do you need to produce $1)
- CO_2/E: carbon emissions per unit of consumed energy

Week 7

12 Life Cycle Assessment (LCA)

LCA is an analytical tool that assesses energy consumption/emissions within a life cycle of a system (e.g. product, energy system, material).

Example: LCA of a reusable water bottle
1. Crude oil extraction, 2. Transportation, 3. Refinery, 4. Manufactory/Assembly, 5. Transportation to consumption, 6. Use, 7. Disposal

12.1 Precision vs. Accuracy

12.1.1 Precision

Precision describes how close repeated measurements are to each other. A method is precise when it produces very similar results under the same conditions.

Precision = Reproducibility

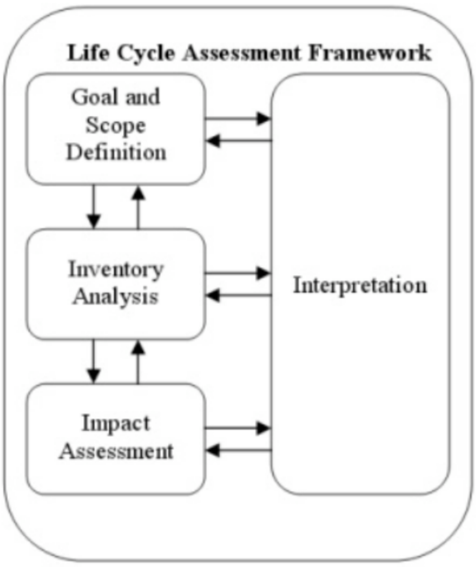
Bias = inaccuracy / fixed error

12.1.2 Accuracy

Accuracy describes how close a measurement is to the true or accepted value. Accuracy is only meaningful when the result is also sufficiently precise, because a correct value obtained by chance is not reliable.

12.2 Four phases of LCA

1. Goal and scope definition
2. Inventory Analysis (LCI): compiling relevant inputs and outputs
3. Impact Assessment (LCIA): evaluating potential environmental impacts associated with the inputs and outputs
4. Interpretation: evaluation of results (LCI and LCIA) in relation to objectives of LCA



12.2.1 Goal and scope definition

- **Breadth and depth of the study is defined**
- Goal should include statement of the reason for carrying out the LCA

- Scope should include the following:
  - Function of the considered system
  - Check for fixed bias (a measurement tool that gives you always the same fixed error)
  - System boundaries (including assumptions and limitations)
  - Data requirements
  - Type of impact assessment methodology (LCIA)
- Funcional unit:
  - **It is needed to normalize the output so that can be compared with other outputs with the same functional unit**
  - Provides reference to which the inputs and outputs (inventory analysis) can be related to
  - Enables possibilities for comparison between different systems

Tools for analysing energy systems

- Requires estimate of in- and outflow values for each stage of the life cycle
- It is partly very difficult to accurately estimate these values for each activity (e.g. energy consumed in individual stage)
- If no educated guess can be made, stage must be explicitly excluded from the LCA
- LCA can be performed from “cradle to grave” → From resource extraction to disposal phase
- Or from “cradle to cradle” → End-of-life disposal step for product is a recycling process

12.2.2 Life cycle inventory analysis (LCI)

- **Collection of the input data**
- Accounting of all processes involved in the system of interest
- Determination and quantification of all in- and outflows of the system:
  → Raw resources or materials
  → Types and amount of energy
  → Water use
  → Emissions to air, water and land by specific substance

Overview of different stages within life cycle

Resource extraction	Transportation raw material	Conversion of raw material
Product manufacturing	Product transportation	Commercial “overhead”
Infrastructure construction and maintenance	Product use phase / consumption	Demolition / disposal / recycling

12.2.3 Life cycle impact assessment (LCIA)

Evaluation of magnitude and significance of potential environmental impacts.

Classification and characterization

- Selection of relevant impact categories (based on goal an scope)
- Impact potentials are calculated

Normalization and weighting

- Both steps are voluntary according to ISO standard (ISO 14040)
- Normalization provides basis for comparing different types of environmental impact categories (same unit is assigned)
- Weighting assigns a weighting factor to each impact category depending on relative importance

LCIA - Impact categories (ICs)

- ICs represent environmental issues of concern
- LCI results are assigned to various ICs
- Possible ICs:
  Global warming / climate change, Acidification, Smog formation, Stratospheric ozone depletion, Eutrophication, Human carcinogenicity, Ecotoxicity (aquatic, terrestial)

12.3 Interpretation: Eco-indicator 99

Eco-indicator assesses seriousness of three damage categories:

1. **Damage to human health**:

   → Expressed as the number of years life lost and the number of years lived disabled

   → Combined as Disability Adjusted Life Years (DALYs)

2. **Damage to ecosystem quality**:

   → Expressed as loss of species over a certain area during a certain time (using for instance CO_2e)

3. **Damage to resources**:

   → Expressed as surplus energy needed for future extractions of fossil fuels and minerals

12.3.1 Damage model for resources

- Extracting minerals reduces quality of remaining resources → High quality resources are extracted first (high ore grade)
- Damage to resources will be experienced by future generations → More effort (energy) required to extract same amount of resources; Expressed as "surplus energy"

12.3.2 Damage model for land-use (ecosystem quality)

- Mankind occupies large areas for urban and agricultural purposes → Degradation of natural habitat; increased species extinction rate
- Different types of land-use have different effects
- Scale expresses decrease in species diversity per type of land use

12.3.3 Damage model for human health - emissions

Subdivided in 4 steps:

Fate analysis

- Chemical substances are released into the air, water and soil (compartments)
- Where substance will go and how long it remains there depends on properties of substance and compartment
- Fate analysis models transfer between compartments and degradation (lifetime) of substance (calculating concentrations in air and water)

Exposure
Based on concentration levels, it is determined how much of a substance is actually consumed by living organisms.

Effect analysis
Based on exposure level diseases and other harmful effects and there frequencies are predicted.

Damage analysis
Predicted diseases are expressed as damage unit:

- For humans expressed as DALY
- For toxic effects on ecosystems percentage of exposed plants and species is determined
- For acidification and eutrophication percentage of plants which is likely to disappear is determined

It is important to determine the correct scale of impact (locally or globally).

Week 8

13 LCA modelling

13.1 Product

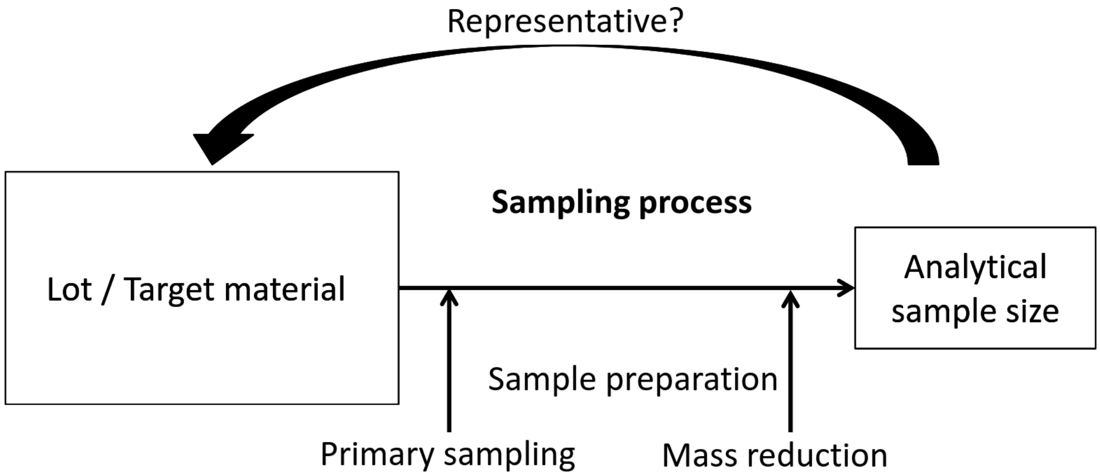
It is what serves the process, for instance plastic, metal, aluminum, crude oil. The raw, virgin material is a product.

13.2 Process

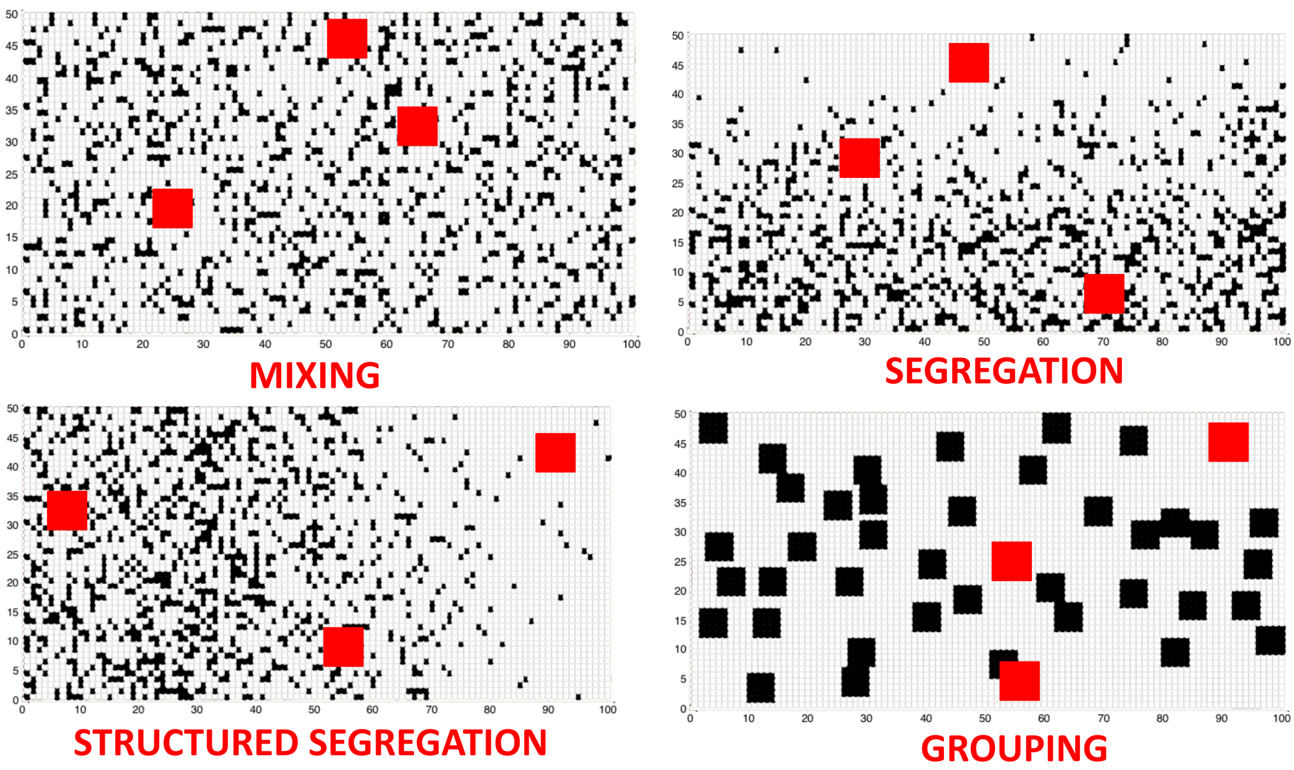
A process creates the product. Whenever a product is transported, refined, modelled, molded.

14 Representative sampling for environmental QCQA

QCQA = Quality Control and Quality Assurance



14.1 Material heterogeneity



15 Theory of Sampling (TOS)

1. Fundamental understanding of the concept of: **Heterogeneity**
2. Full knowledge about different types of: **Sampling errors**
3. Practical understanding of: **Sampling Unit Operations**
4. Ability to analyze sampling problems/issues: **Heterogeneity Characterization**

15.0.1 Sampling practice

TOS = 6 General Principles (GPs) + 4 Sampling Unit Operations (SUOs)

General Principles
GPs are normally used in design, planning, optimization of new sampling processes

- FSP: Fundamental Sampling Principle
- LDT: Lot Dimensionality Transformation
- PSC: Sampling Correctness (bias-free sampling)
- SSI: Sampling Scale Invariance
- PSS: Sampling Simplicity (primary sampling + mass reduction)
- LHC: Lot Heterogeneity Characterization

Sampling Unit Operations
SUOs are used as active steps in the sampling process (often used several times + in combination)

- SUO 1: Composite Sampling
- SUO 2: Mixing / Blending
- SUO 3: Comminution
- SUO 4: Mass Reduction (Sub-sampling)

15.1 TOS' basic terms

15.1.1 Lot / Sampling Target / Decision Unit

The complete entity of the original material being subject to sampling e.g. truck load, process stream, ships cargo, bags etc. The lot (sampling target) refers both to the physical, geometrical form and size, as well as the material characteristics of the material being subject to sampling.

Dimension of the Lot

3-dim 2-dim 1-dim

Increment
Correctly delineated and materialized unit of the lot which, combined with other increments, provides a composite sample.

Sample
Correctly extracted material from the lot, which can only originate from a qualified 'correct' sampling process. Composite sample consists of various increments.

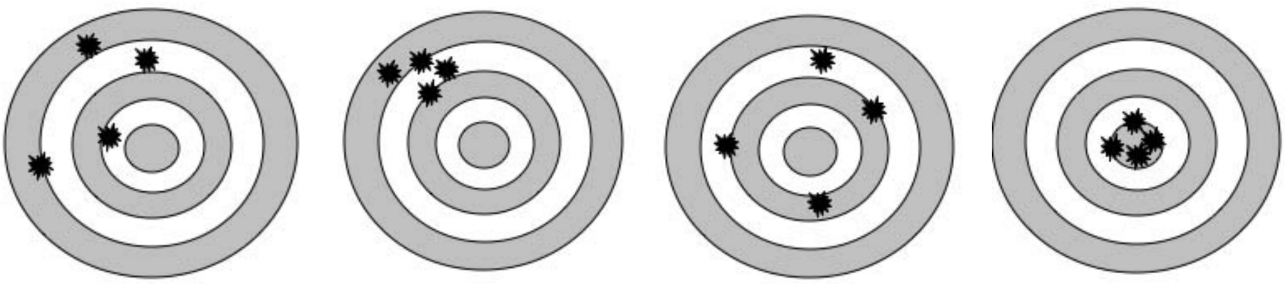
Specimen
A 'sample' that cannot be documented to be representative (because it cannot be associated with a representative sampling process).

Fragment
Fragment refers to the smallest separable unit of the lot that is not affected by the sampling process itself (e.g. particles, molecules, grains, etc).

Group
A number of spatially correlated fragments, which act as a coherent unit during sampling operations.

Representative Sample
! Sampling bias is not of the same nature as analytical bias !

- Must be based on correctly delineated and materialized unit of the lot
- Must be based on combination of increments (composite sample)
- A sample can only be representative if the sampling process is both accurate (systematic part) and precise / reproducible (random part)



Not accurate, Not precise | Not accurate, precise | Accurate, not precise | Accurate, precise

Relative sampling error

$$e = \frac{aS - aL}{aL}$$

where:

- aL = analytical grade of the lot (grade = mass of analyte divided by the total mass of the lot)
- analytical grade of the sample (mass of analyte divided by the total mass of the sample)

Analyte
An analyte is the specific substance or chemical component in a sample that is being identified or measured.

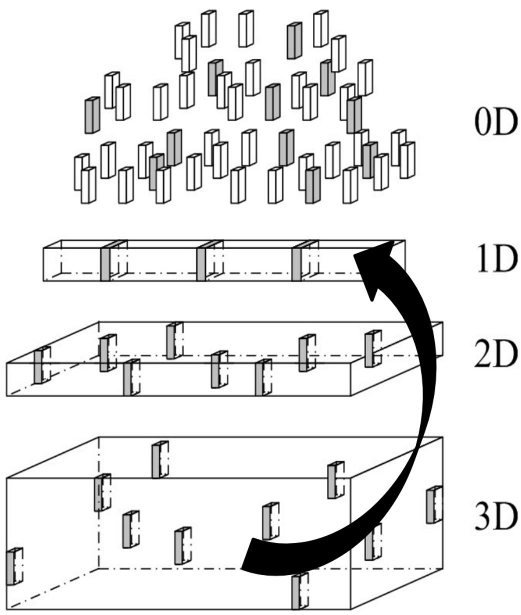
16 General Principles (GPs)

16.1 FSP: Fundamental Sampling Principle

- All possible extractions from the lot (all possible virtual increments) must have the same (non-zero) probability of ending up in the sample
- FSP implies physical access to all geometrical units of the lot (access to all the dimensions)
- FSP must never be compromised, otherwise possibility of documenting accuracy of the sampling process is impossible

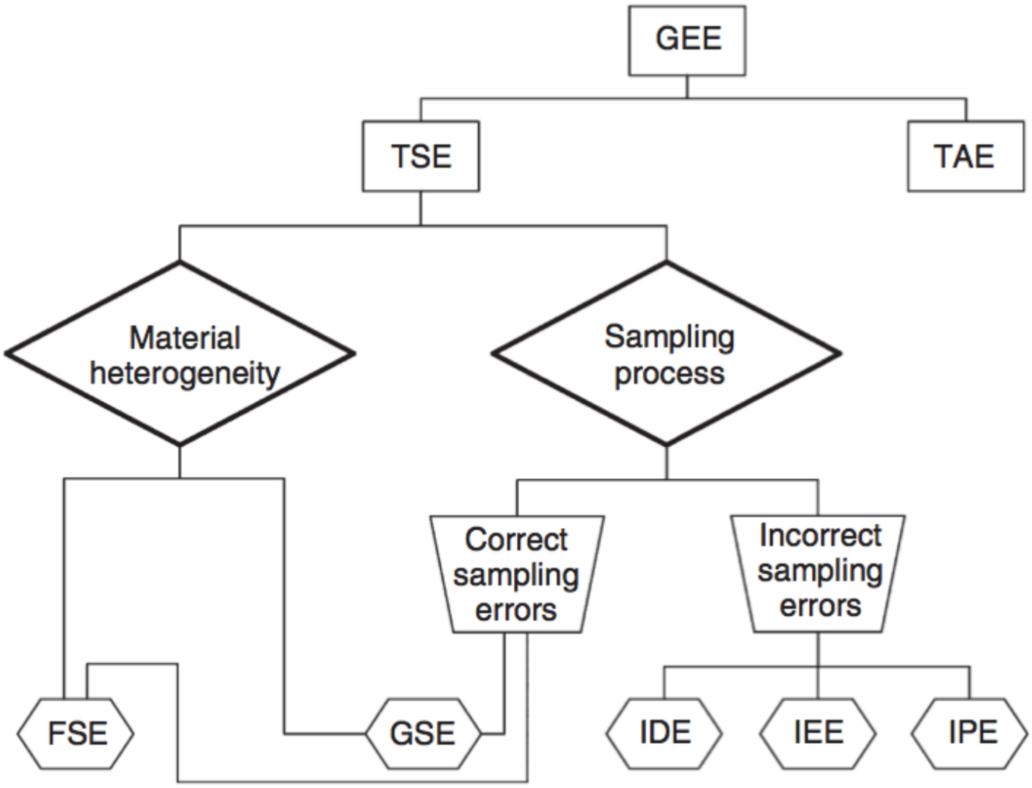
16.2 LDT: Lot Dimensionality Transformation

- No correlation exist and the increments or fragments can be mixed (any increment can be picked - more or less - freely)
- Increments fully covers two of the lot dimensions (e.g. a "slice")
- Increments fully covers one of the lot dimensions (e.g. a drill-core)
- Increments do not fully cover any of the lot dimensions (e.g. a "stock pile")



16.3 PSC: Principle of Sampling Correctness (bias-free sampling)

"A sample can only be representative if the sampling process is both accurate (bias-free) and precise"



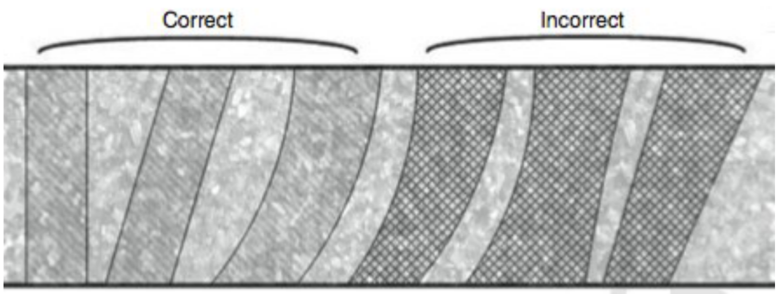
where:

- GEE = Global Estimation Error
- TSE = Total Sampling Error
- TAE = Total Analytical Error (e.g. ±5%)

16.3.1 Incorrect sampling errors

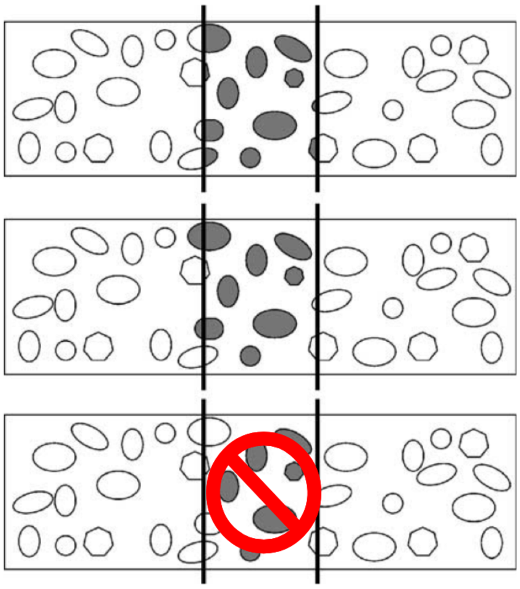
IDE: Increment Delimitation (delineation) Error

- IDE relates to the physical extraction of the increments
- IDE can be avoided by delineating an increment which covers the relevant dimensions of the lot
- For 1-D lots a correctly delineated increment consists a complete cross-sectional slice of the material stream



Top-view of a conveyor belt

IEE: Increment Extraction Error
IEE occurs when particles inside the delineated increment do not end up in the sample, also referred to as the "centre-of-gravity rule".



IPE: Increment Preparation Error

- IPE arises when increments/samples are altered after extraction, e.g. contamination, evaporation, moisture absorption, loss of material (spillage), and also deliberate manipulation (fraud, sabotage)
- Samples always need to be air-tight sealed, labeled and documented

Sampling process results
After sample extraction no possibility exists to proof whether a sample is representative (of the lot) or not.

→ It must be ensured that the sampling process itself is representative (elimination of all bias-generating sampling errors)

16.3.2 Correct sampling errors

- Correct sampling errors cause random effects (imprecision) due to material heterogeneity effects
- Can never be completely eliminated but should be reduced as far as possible

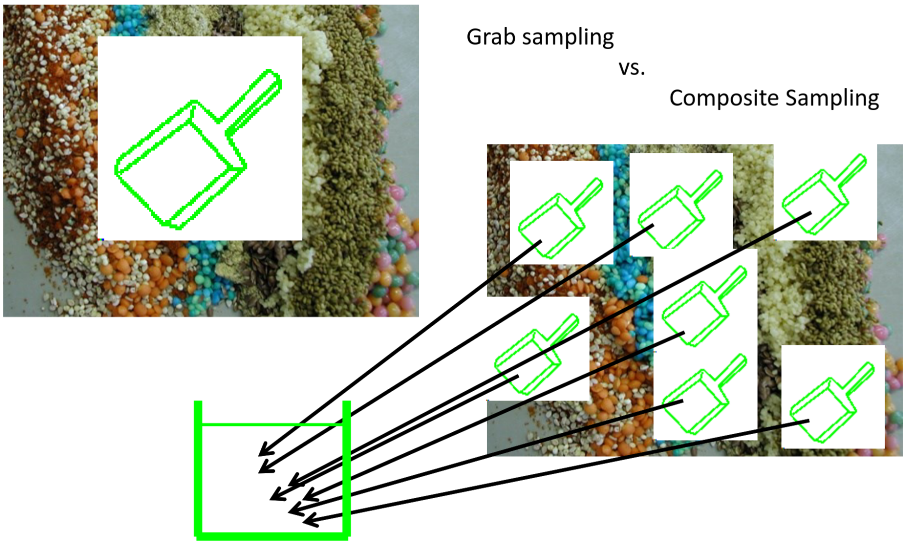
Total material heterogeneity in a lot must be distinguished as two components:

1. **Constitutional (compositional) heterogeneity (CH)**
2. **Distributional heterogeneity (DH)**:
   - DH_L reflects the irregular spatial distribution of the analyte
   - DH_L is caused by the inherent tendency of particles to cluster and segregate locally (grouping) and more pervasively throughout the lot (segregation)
   - In TOS, this is viewed as reflecting the Grouping and Segregation Error (GSE)
   - DH_L can be counteracted by the process of mixing (SUO 2) and/or by suitably-deployed, problem-dependent composite sampling (SUO 1) with a sampling tool allowing a high number of increments

16.3.3 Sampling Unit Operations (SUOs)

SUO 1: Composite Sampling

- Composite Sampling reduces Grouping and Segregation effects
- Heterogeneity is many times not observable with the naked eye
- Composite samples need often mass reduction → representative mass reduction (SUO 4)



SUO 2: Mixing / Blending

Mixing is trivial but important process (decreases segregation effects - GSE) - still NO excuse for grab sampling

Mixing reduces contributions to sampling variation from the Grouping and Segregation Error (GSE):

$$s^2((\text{GSE}) = \zeta \cdot \gamma \cdot s^2(\text{FSE}))$$

where ζ is the Segregation factor and γ is the Grouping factor (unaffected by mixing - reduced only by selecting smaller increments)

Constitutional heterogeneity (CH)

- CH describes the heterogeneity depending on the chemical and/ or physical differences between individual "constituent units" in the lot (e.g., particles, grains, or kernels)
- When a lot (L) is sampled, CH_L manifests itself in the form of the Fundamental Sampling Error (FSE) effect
- CH_L increases when the compositional difference between fragments increases; CH_L can only be reduced by comminution/crushing (SUO 3)

SUO 3: Comminution

FSE can be reduced (never eliminated) by particle size reduction (crushing)

SUO 4: Mass Reduction (sub-sampling)

Representative sampling is always a multistage process → Mass reduction is as important as primary, secondary [...] sampling

Mass reduction method / device can have influence on:
Estimating true concentration (accuracy), Sampling variation (precision / reproducibility), Time consumption, Ease of cleaning, Loss of material, User dependency, Cost

16.4 SSI: Sampling Scale Invariance

Theory of Sampling is scale invariant; all principles need to be followed independent of lot and increment size.

16.5 PSS: Sampling Simplicity (primary sampling + mass reduction)

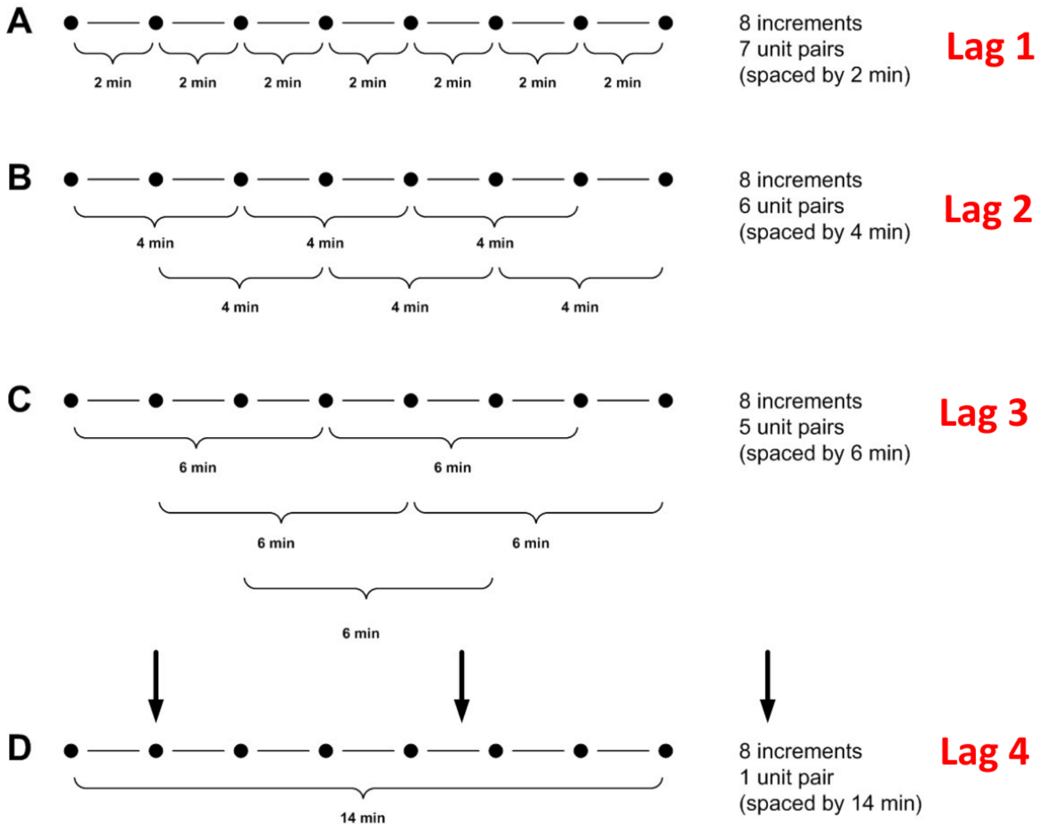
1. Sampling is never a one-shot operation
2. Sampling is always a multi-stage process: Primary sampling + Representative Mass-reduction

16.6 LHC: Lot Heterogeneity Characterization

- An appropriate sampling procedure can only be designed knowing the lot heterogeneity quantitatively
- For 3-dimensional/stationary lots: A replication experiment will reveal Total Sampling Error as well as sampling steps generating the largest variance
- For 1-dimensional lots: Complete empirical sampling error estimation - variographic analysis

16.6.1 Variographic Analysis (Variography)

- 1-dimensional heterogeneity characterization
- 1-D lots: processes, long stationary piles, ordered series etc.
- Valuable information about lot variation (trends, periodic phenomena, shifts)



Lag is the distance between increments (samples) along the time or spatial dimension

A variogram displays the total variation as a function of the lag

Variography procedure
Lag 1:
Increment 1 is compared with Increment 2, Increment 2 is compared with Increment 3, ..., Increment i is compared with Increment $i+1$

Lag 2:
Increment 1 is compared with Increment 3, Increment 2 is compared with Increment 4, ..., Increment i is compared with Increment $i+2$

Lag 3:
Increment 1 is compared with Increment 4, Increment 2 is compared with Increment 5, ..., Increment i is compared with Increment $i+3$

Lag n:
Increment 1 is compared with Increment $1+n$, Increment 2 is compared with Increment $2+n$, ..., Increment i is compared with Increment $i+n$

Week 9

17 Multi-criteria decision analysis (MCDA/MCA)

Complex decisions require various inputs:

- Data (measurements, observations, experiences etc.)
- Risk analysis (what effects might a certain decision have?)
- Cost analysis (or CBA)
- Preferences of certain stakeholders

MCDA is a mathematical methodology incorporating values of decision makers to select best solution for a certain problem → Scientifically defensible decision

- Multi-criteria analysis identifies criteria for choosing the best alternative among competing projects or products
- Criteria may include air/water pollution, GHG emissions, EROI, economic value, social criteria, etc.
- All criteria are evaluated on common basis allowing comparison between criteria and alternatives → overall multi-criteria score

Steps for MCDA

- Define aim and scope of analysis
- Selection of decision criteria and weight scale
- Calculation of scores for each criterion
- If weight scale is modified → recalculation of criteria weights
- Interpretation of results and sensitivity analysis

17.1 MCDA structure

1. Problem identification → Defined in terms of overall structure and relevant stakeholders
2. Problem structuring:
    - Definition of alternatives and criteria
    - Criteria are set of properties that describe alternative performance (e.g. cost, efficiency, environmental impact)
3. Assessment:
    - Alternatives and criteria are given numerical values (e.g. LCA, cost assessment, risk assessment, long-term impact)

- Alternatives are scored against the criteria
- Criteria can also be weight according to value or importance

4. Initial results and sensitivity analysis
5. Decision/planning → MCDA output is used to make decision or further planning

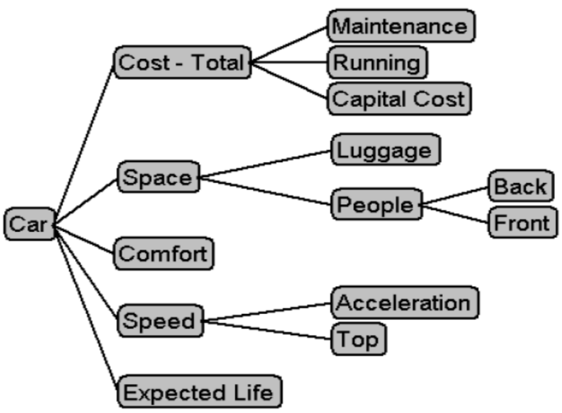
17.1.1 Problem identification

Focussing questions:

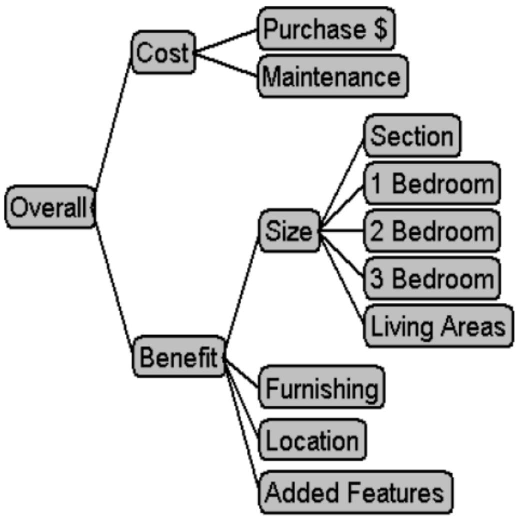
- What is the significance of the problem?
- Can the problem be broken down into key components (criteria)?
- Does the problem involve several alternatives that need to be compared?
- Are alternatives already known or is further research required?
- What is the pre-conceived judgement of the problem?

17.1.2 Problem structuring

- Identifying (decision) criteria → Purpose is to develop hierarchical "value tree"
- Pre-emptive criteria are used to screen out alternatives before the comparison:
  → Only alternatives in a certain cost range are considered
  → Pre-emptive criteria are not shown in value tree
- Level of detail within tree hierarchy should be balanced
- Avoid criteria that measure the same attribute



CAR SELECTION



PURCHASING A HOUSE

Focusing questions

- Which are the alternatives?
- Do unknown alternatives exist?
- Do certain alternatives overlap → can they be grouped?
- Which criteria exist to evaluate the differences between certain alternatives?
- Are these criteria pre-emptive (if yes, which alternatives can be screened out?)
- What is the logical hierarchical structure of the criteria (e.g. purchase price, maintenance)

17.1.3 Assessment

Assignment of numerical values to criteria and alternatives.

Decision on applied scale (e.g. ordinal, interval, ratio):

1. Ordinal is the measurement of consumers satisfaction:
   - Very dissatisfied, somewhat dissatisfied, somewhat satisfied, very satisfied
   - Allows comparison but does not capture difference between two levels
2. Interval is numerical scales in which intervals have the same interpretation:
   - E.g. Celsius scale of temperature (difference between 10 and 15 degrees represents same temperature difference as between 0 and 5)
   - 5-degree interval has same physical meaning (kinetic energy of molecules)
3. Ratio is the most informative scale:
   - Interval scale with zero position (absence of quantity being measured)
   - E.g. amount of money in your wallet
4. Selection of scale depends on data characteristics (quantitative, qualitative)
5. Linear vs non-linear scale:
   - E.g. an ideal house size does not need to be the largest/smallest option
   - Most preferred value could occur in the middle range of measured values

Focussing questions

- What data is available?
- Quality of available data?
- Do some criteria require qualitative scoring?
- Do certain criteria require non-linear scales?
- How can numerical values (with different units) be translated into a score (no unit)
- Can each criteria be scored on its own without considering other criteria? If not criteria/value tree should be redefined

17.2 Multi-criteria analysis

The weighing of the criteria have an important impact on the outcome of the analysis → (Environmental) weight sets have been developed in various research studies

Week 10

18 Ecosystem services

Week 11

19 Geographic Information System (GIS)

19.1 Framework vs Tool

Framework
A framework is a structured foundation that provides rules, components, and a predefined way to build something.

Tool
A tool is a specific instrument or software used to perform a particular task.

19.2 What is GIS

19.2.1 Definition

A geographic information system (GIS) is a framework for gathering, managing, and analyzing data. It analyzes spatial location and organizes layers of information into visualizations using maps.

Geographic: relates to the surface of the earth

Information: is knowledge derived from study, experience, or instruction

System: is a group of interacting, interrelated or interdependent elements forming a complex whole

19.2.2 Spatial data

Information about locations and shapes of geographic features and the relationships between them.

19.2.3 Applications

Natural environment:

- Forestry
- Modelling of habitats
- Habitat protection
- Environmental impact assessment
- Landscape protection
- Management of natural resources
- Modelling of emissions
- Modelling of natural hazards
- etc.

Anthropogenic environment:

- Local and regional planning
- Selection of company locations
- Population statistics
- Infrastructure management
- Landscape protection
- Planning of electricity grids
- Route selection and fleet management
- Vehicle navigation
- etc.

19.2.4 GIS tasks and questions

Task	**Question**
Localisation/Orientation	What can be found at this location (e.g. shops, restaurants etc.)?
Thematic query	Which agricultural areas are used for vegetable cultivation? (and where are they situated?)
	Which municipalities have more than 10'000 inhabitants? (and where are they situated?)
Temporal query	How has forest area changed since 1900?
Spatial query	How many people in Wales live 300 meters away from a mobile communications antenna?
Network analysis	What is the fastest way from Zurich to Geneva?
Simulation of processes	How would a forest fire spread or which path would a lava stream follow?
Decision support	Which areas would be affected by the bursting of a dam and where would be safe evacuation routes?

19.3 GIS components

19.3.1 Data

- Data provides information used within a GIS
- A GIS often incorporates data from multiple sources:
  - Accuracy defines the quality of the GIS

- GIS quality determines the level of detail of questions/problems that may be asked/answered

- Data sources might be: Remote sensing, Paper maps, Statistical reports, Databases, ...

19.3.2 Remote sensing (RS)

- Obtaining information in one place without physically being there
- RS methods: airplane, satellite, drone etc.
- RS cameras can see things beyond human vision (between ~400 - 700 nm) → From short wavelengths (like X-rays) to long wavelengths (like radio waves)
- Each object has its own unique spectral signature, depending on its chemical composition

Active RS
Active instruments provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe

Passive RS
Passive sensors detect natural energy (sunlight) that is reflected or emitted from the observed scene

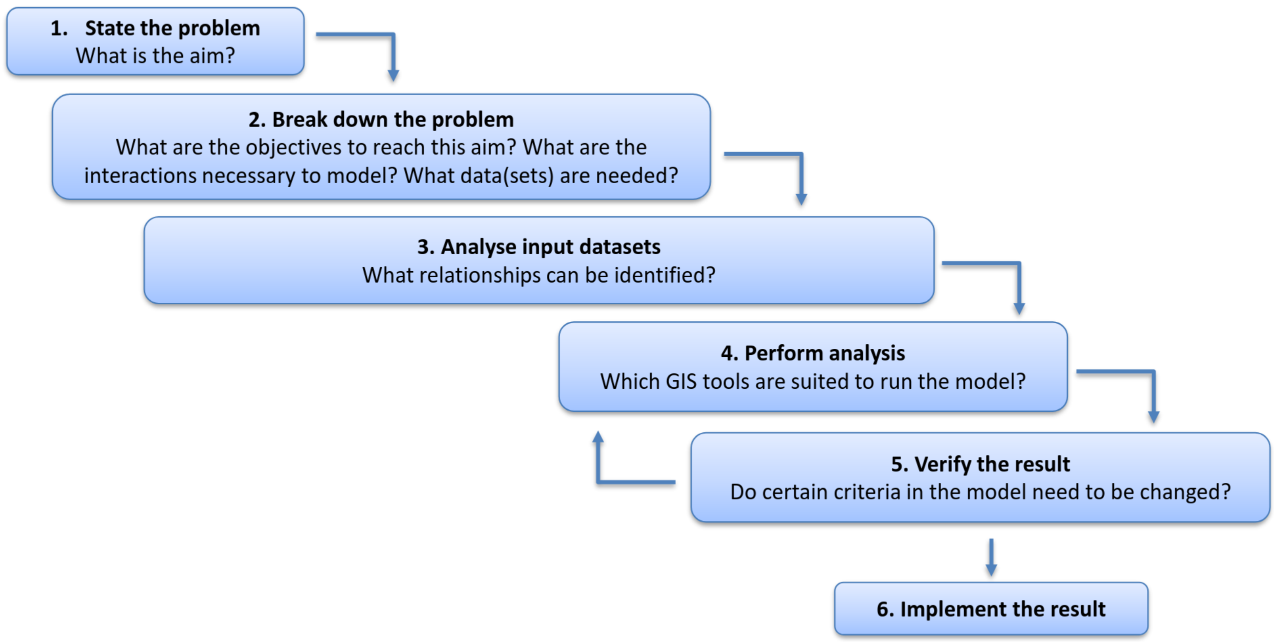
19.3.3 Software

- Standard software includes packages used for databases, drawings, statistics and imaging
- Software used must match the needs and skills of the end user
- Most popular GIS software programs are ArcGIS (commercial) and QGIS (open source)

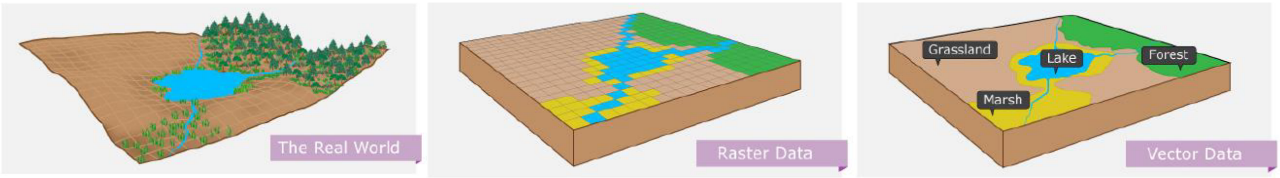
19.3.4 Hardware

Type of hardware determines speed at which a GIS will operate (may influence type of software used)

19.3.5 Method



19.3.6 Picture methods



Each feature (point, line, polygon or raster) within a GIS layer is represented as an entry in a data table

Raster picture
A geographic feature (e.g. land cover) is represented as single square cells

Vectorial picture
Features are represented as points, lines, polygons

19.3.7 Raster and vector models

	Raster model	Vector model
Advantages	• Remote sensing imagery is typically obtained in raster format → simple data structure: a grid with a code in each cell • Quantitative analysis is more intuitive	• Graphic output is generally more aesthetically pleasing • Higher geographic accuracy because data is not dependent on grid size • Network analysis and proximity operations use vector data structures
Disadvantages	• Pixelated look, linear features and paths are difficult to display • Raster datasets can become very large → they record values for each cell in an image	• Usually substantial interpolation is required for these data layers

Week 12

20 Non-renewable energy sources

- Non-renewable energy resources cannot be replaced once they have been used
- Will not be restored (at least not for millions of years)
- Non-renewable energy resources include fossil fuels and nuclear fuels

21 Characteristics of fossil fuels

21.1 Definitions

21.1.1 Fossil fuels

A fuel (such as coal, oil, or natural gas) that is formed in the earth from dead plants or animals.

Any naturally occurring carbon or hydrocarbon fuel that is formed by prehistoric decomposition of organisms (millions of years): coal, natural gas and petroleum. Petroleum refers both to unprocessed crude oil and refined petroleum products

21.1.2 Nuclear fuels

Nuclear fuels release energy by nuclear fission or (nuclear fusion). Most common nuclear fuels (radioactive metals) are uranium and plutonium.

21.2 Usage

In contrast to natural gas and petroleum, coal cannot be combusted directly in internal combustion engines. Coal is not used in transportation, but in stationary applications (e.g. electricity generation). Coal is also used in small-scale domestic applications (e.g. cooking, space heating)

Gas and oil can be combusted directly: Both are used for transportation and stationary applications. Gas requires modest amount of purification. Crude oil is refined into a range of end products (e.g. petrol, kerosene, lubricating oil, heavy oil).

21.3 Energy density

- Energy density = amount of energy per unit (mass or volume) available in a resource
- Using fuels with low energy density requires greater amount of fuel to achieve certain energy output
- Energy density of coal is measured in GJ/tonne (or million BTU/tonne)
- Energy density of oil is measured in GJ/barrel (or million BTU/barrel)
- Energy density of natural gas is measured in MJ/m^3 (or BTU/ft^3) at atmospheric pressure

21.4 Estimated reserves and resources

21.4.1 Reserve

Proven quantity of a fossil fuel that is known to exist in a given location

21.4.2 Resource

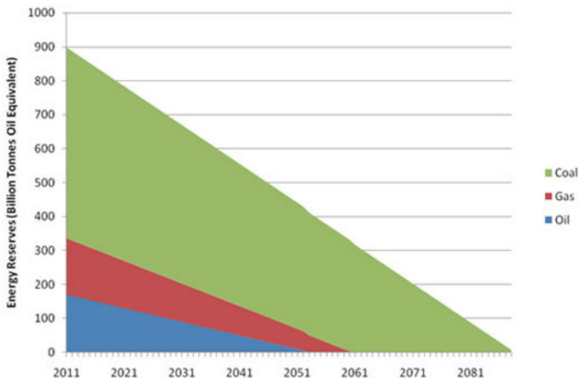
Estimated quantity of fuel that has yet to be fully explored and evaluated.

For each fuel an additional quantity of resource is available (depending also on available extraction technology).

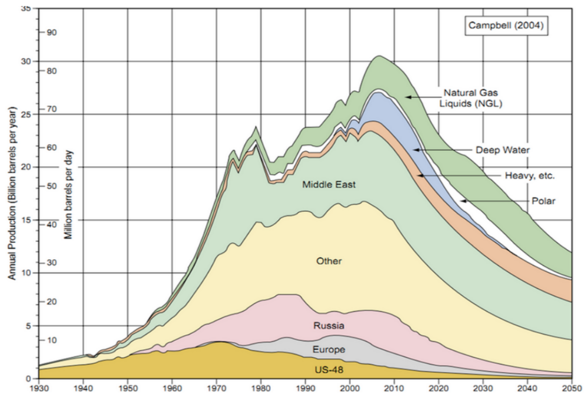
21.5 Reserve exhaustion

- Linear model of resource exhaustion is not realistic
- Availability/exhaustion of reserves are depending on reserve-to-consumption ratio
- Individual oil and gas fields and coal mines typically follow a life cycle → Productivity grows first, peaks and then begins to decline as wells/mines become less productive
- Worldwide production of a fossil fuel follows same pathway

Linear reserve:



Hubbert curve:



22 Fossil fuels - coal

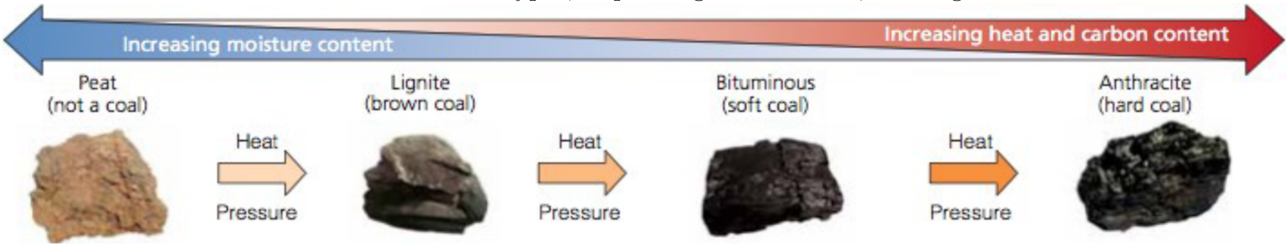
22.1 Formation and extraction of coal

- Coal consists mainly of carbon, but contains elements such as hydrogen, oxygen, nitrogen, sulphur as well numerous minerals
- Coal was mainly formed during the Carboniferous period:

  - Large amounts of organic materials grew in swamp like conditions
  - Dead organic matter drifted to bottom of swamps and was slowly decomposed and turned into peat
  - Over millions of years peat was compressed and turned into coal (by pressure and heat) → The higher heat and compression level, the higher the level of carbon (coalification)
- Formation of coal is an on-going process

22.2 Ranking of coal

Coal can be broken down into four main types, depending on moisture, heating value and carbon content.



Lignite
Contains 25% - 35% carbon and has the lowest coal heating value

Sub-bituminous coal
Contains 35% - 45% carbon and has slightly higher heating value than lignite coal

Bituminous coal
Contains 45% - 86% carbon and has the highest heating value

Anthracite (black/hard coal)
Highest concentration of carbon (between 85% - 97% carbon), slightly lower heating rate than bituminous coal

22.3 Extraction techniques

22.3.1 Surface mining

- Surface mining consists of mining no deeper than 200 feet (approx. 60m)
- Surface mining is much cheaper than underground mining
- Large machinery is required to remove topsoil and large layers of rock to expose coal beds
- Once coal has been mined normally rock and topsoil is moved back
- Type of surface mining depends on two factors: resource and local topography

22.3.2 Open-pit mining

- Mainly used for extracting metal ores (e.g. gold, iron) and stone (e.g. marble, limestone)
- Machines dig holes and remove resource

22.3.3 Strip mining

- Used for mineral deposits that lie close to the earths surface in large horizontal beds
- Gigantic earthmovers strip away the overburden and remove mineral deposit

22.3.4 Contour strip mining

- Mostly used for coal (located in different coal layers)
- Huge shovels cut terraces into the side of a hill
- Earthmover removes overburden to extract the coal

22.3.5 Underground mining (subsurface mining)

- More expensive and dangerous option
- Allows coal extraction from more than 1,000 feet (300m)
- Two large shafts are drilled into the ground:
    1. First allows transport of miners and machinery to the coal
    2. Second shaft is used to transport mined coal to surface

22.4 Trasportation of extracted coal

After mining, coal is crushed into manageable pieces.

Transport methods for coal: railway, truck, conveyors, and by cargo ship

23 Environmental impacts of mining

23.1 Surface mining

- Disturbed land, which is susceptible to chemical weathering and erosion by water and wind and leads to slow regrowth of vegetation
- Major air and water pollution:
    - Wind and water erosion can spread mining waste deposit
    - Acid mine drainage - rainwater seeping through a mine deposit to nearby streams and groundwater
    - Emission of toxic chemicals into atmosphere
- Noise and visual pollution
- Surface mining sites can be cleaned up and restored → very costly

23.2 Subsurface mining

- Disturbs less than one-tenth as much land as surface mining
- Less waste material is produced
- Lower recovery rate (more resources are left in the ground)
- More expensive and dangerous than surface mining
- Potential hazards: explosions, fires, cave-ins, diseases (black lung), subsidence (collapse of land above some underground mines)

24 Consumption of coal

Coal is primarily used for: Electricity production, Steel/cement production, General industry (e.g. chemicals, paper)

24.1 Coal price

Coal is the cheapest fossil fuel and price (USD/ton) is relatively stable

25 Measures for minimizing air pollution

25.1 Preventive measures

- Selection of suitable coal fuel type
- Most important coal quality characteristics are: carbon content, moisture content, suphur content, nitrogen content

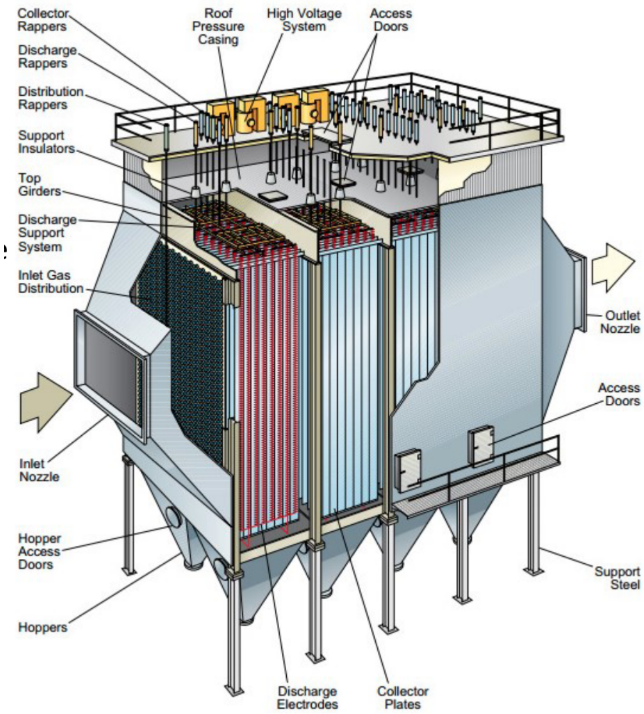
25.2 Control measures

- Modern power plants are able (depending on coal type) to remove:
  - $> 80\%$ of NO_x
  - $> 90 - 95\%$ of SO_2
  - ~99% of incombustible parts (fly ash)

25.2.1 Removal of fly ash: Electrostatic precipitator

Flue gas is forced though two electrodes:

- First electrode is charged negatively
- Second electrode charged to a high positive voltage → Negatively charged particles stick to collector plates
- Collecting plates are shaken or brushed in regular time intervals (rapping)



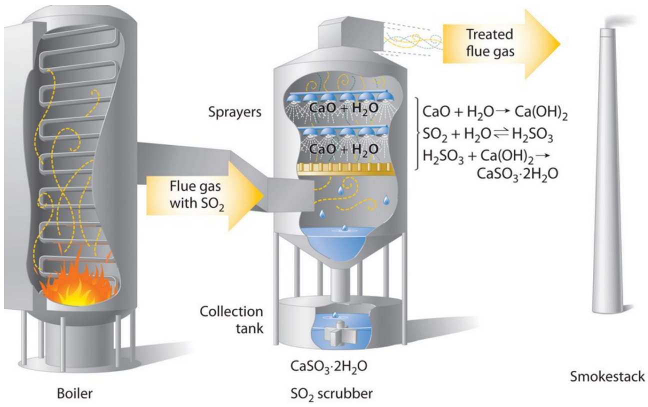
25.2.2 Removal of SO_2: Flue gas desulphurization (FGD)

Different technologies exists to remove SO_2 from the flue gas:

- Wet scrubber systems (most used FGD technology)
- Semi-dry scrubber systems
- Dry systems

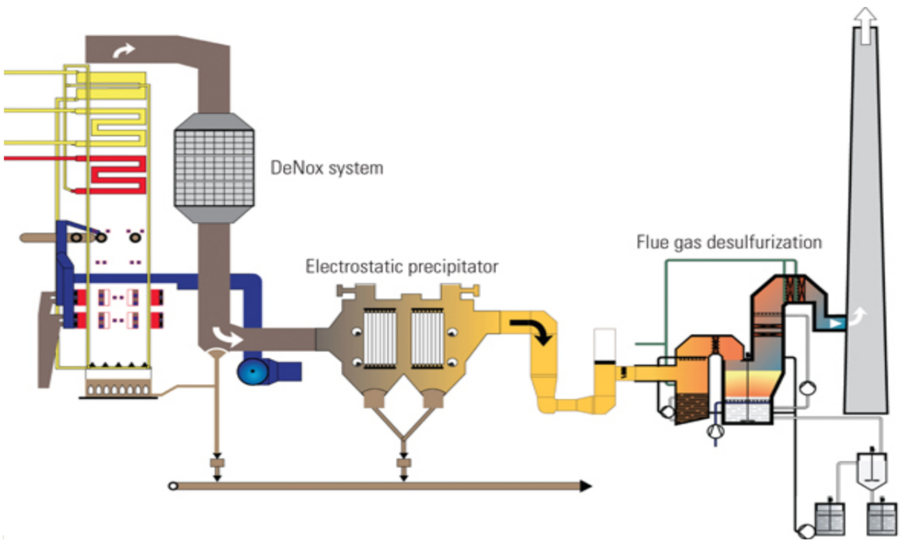
Wet scrubbing

- Flue gas is ducted to a spray tower
- Aqueous sorbent (slurry between water and sorbent) is injected into the flue gas
- Typical sorbent materials are limestone (calcium carbonate) or lime (calcium oxide)
- Creates gypsum (used in construction and cement industry)



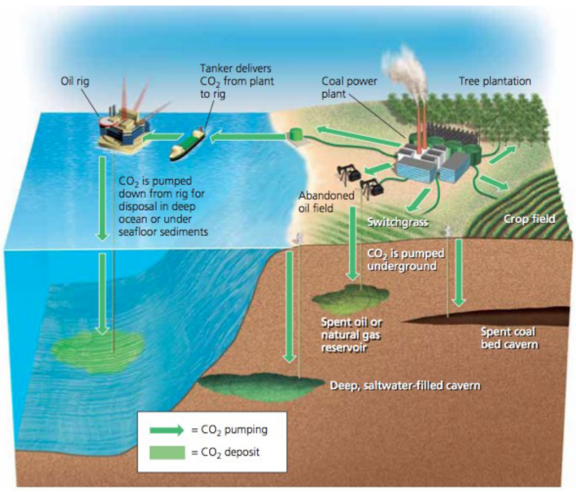
25.2.3 Removal of NO_x - DeNO_x process

- NO_x is formed during combustion process when nitrogen reacts with oxygen in high temperatures
- NO_x level in flue gas is reduced by injecting ammonia (NH_3)
- Reaction creates nitrogen (natural component of atmosphere) and water vapour



25.2.4 Removal of CO_2 - Carbon capture and storage (CCS)

- Removing CO_2 from smokestacks of coal power plants and industrial plants
- CO_2 gas is pumped into underground coal beds or abandoned oil and gas fields
- CO_2 gas can also be liquefied and injected into thick sediments under the sea floor
- CO_2 is pumped to fields and tree plantations for fertilization



Problems with CCS

- CCS power plants are much more expensive than conventional coal-power plants
- CCS is still an unproven technology that might remove only parts (perhaps 25-35%) of the CO_2 emissions
- CCS process is energy intensive → cancels out some of the gains made
- CCS promotes continued use of coal
- No leaks are allowed → Stored CO_2 needs to remain sealed forever

26 Coal combustion alternatives

26.1 Coal gasification

- Solid coal can be converted into synthetic natural gas (SNG) - coal gasification
- It can be converted into a liquid fuel (e.g. methanol, synthetic gasoline) - coal liquefaction
- Classified as synfuels
- Production of gaseous and liquid fuels requires 50% more coal for equal energy output → 50% more CO_2 to the atmosphere and more than 4 times higher water requirement
- Synfuels have low net energy yield and higher production cost per unit of energy

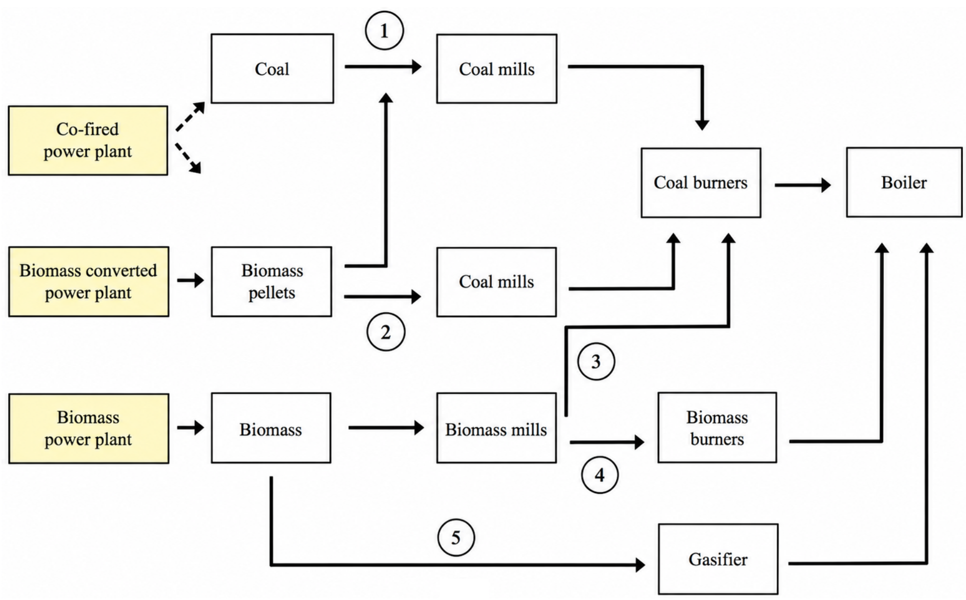
26.2 Biomass

Biomass can be burned directly as solid fuel or converted to liquid biofuel (biodiesel, bioethanol and biogas).

26.2.1 Combustion of biomass for electricity production

- Solid biomass can be used for combustion or co-firing in coal-fired power plants
- Biomass is normally used as chips (wood), pellets (unprocessed or torrefied) or bales (straw)

26.3 Coal-fired power plants to biomass plants



1. Coal is fired together with a modest ratio of biomass pellets
2. Coal power plants that only use biomass as combustion fuel
3. Mills are specially designed for biomass fuels
4. Exchange of original coal burners with specially designed biomass burners
5. Gasification of biomass

Week 12

27 Environmental Economics

27.1 Definition of economics

Economics is the study of production and consumption of goods and the transfer of wealth to produce and obtain those goods.

Economics explains how people interact within markets to get what they want.

Economics is differentiated in macro- and microeconomics:

- Microeconomics focuses on the actions of individuals and industries (e.g. dynamics between buyers and sellers)
- Macroeconomics takes a broader view by analyzing the economic activity of for example an entire country

27.2 Economic system / Direct costs

System through which goods and services are produced, distributed and consumed.

Three types of capital (resources) are used within the economic system:

27.2.1 Human capital

Human capital refers to the knowledge, skills, experience, health, and capabilities of individuals. It includes education, professional training, creativity, problem-solving ability, and the capacity of people to contribute effectively to economic and social activities.

27.2.2 Industrial capital

Industrial (or manufactured) capital includes human-made physical assets used in production processes. Examples include machinery, equipment, factories, buildings, infrastructure, and technological systems that support the creation of goods and services.

27.2.3 Natural capital

Natural capital refers to the resources and ecosystem services provided by nature. It includes renewable and non-renewable resources such as water, soil, forests, minerals, air, biodiversity, and the natural processes that support life and economic activity.

27.3 Indirect costs

Indirect costs are costs caused by production or consumption that are not paid directly by the producer or consumer. They are often shifted to society, future generations or the environment.

Examples of indirect costs:

- Environmental damage, such as air pollution, water pollution, soil degradation and loss of biodiversity
- Health costs caused by pollution, toxic substances, noise or unsafe working conditions
- Climate change costs, such as damage from extreme weather events, sea-level rise and reduced agricultural productivity
- Resource depletion, for example overuse of fossil fuels, minerals, forests, groundwater or fish stocks
- Waste treatment and cleanup costs, such as contaminated land remediation or plastic pollution removal
- Social costs, such as reduced quality of life, displacement of communities or unequal distribution of environmental burdens

These costs are also called external costs or negative externalities, because they are external to the market price. If indirect costs are not included in the price of goods and services, the market price is too low and consumption is higher than the socially optimal level.

27.4 Free-market economic system

- No government inferences (e.g. subsidies, tax)
- Perfect information exchange between buyer and seller (no misleading)
- Prices of goods and services include all direct and indirect costs (e.g. environmental costs)

27.5 Environmental economics

- Environmental economics is a distinct branch of economics
- It acknowledges the value of both the environment and economic activity and makes choices based on those values
- Goal is to balance economic activity and environmental impacts by taking into account all costs and benefits
- Theories are designed to take into account pollution and natural resource depletion → classical economic models fail to do so

27.5.1 Problems with environmental economics

Scarcity

- Historically goods/services provided by the environment were seen to be limitless (not scarce)
- Scarcity is a result of misallocation of these services (which are not limitless)
- Reason is a pricing problem (for free or too low costs) → if resources were properly priced, then they could not be over-exploited, since actual cost would be too high

Open-access resources

- Classical economic system cannot prevent degradation of open-access resources (e.g. clean air, oceans), since they are not bought and sold in the marketplace (market failure)
- Open-access resources are not owned by anyone and are available for everyone
- Opposite are private resources/goods

27.5.2 Types of property / resource right

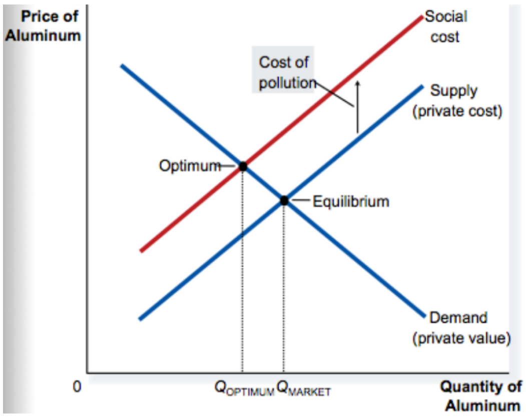
- Private property: A resource is owned by an individual or organization, which can exclude others and control its use.
- Common property: A resource is shared by a defined group, with rules or agreements controlling access and use.
- Open access resources: A resource is available to everyone without effective ownership or restrictions, making overuse likely.

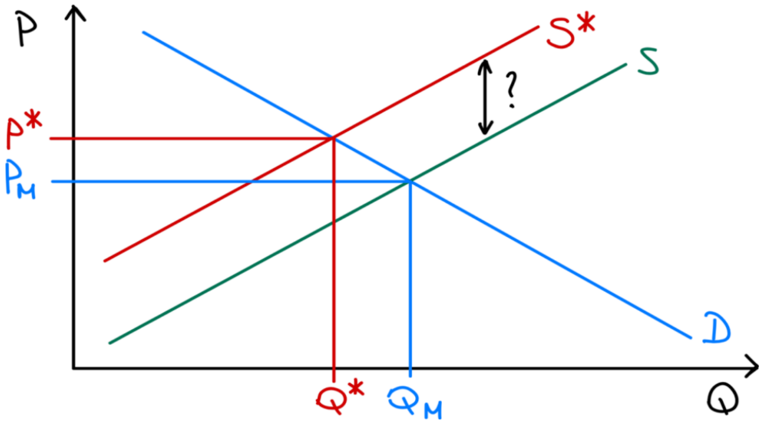
27.5.3 External costs (externality)

- Uncompensated costs of human actions, which needs to be addressed by correcting prices
- Negative externality → Effect on "environment" is adverse
- Positive externality → Effect on "environment" is beneficial

27.5.4 Market failure (negative externality)

- Inability of markets to reflect the full social costs or benefits of a good or service
- Environment provides resources, assimilates waste and provides aesthetic pleasure
- Positive economic value is not recognized by classical economics → Ability to set a price for these services is missing
- Environmental economics is a tool to overcome market failure with respect to resource use and pollution





27.6 Coarse Theorem

- Proposition that if private parties can bargain without cost over the allocation of resources, the problem of externalities is solved on its own
- Example: Mark owns a dog, which is barking constantly which disturbs Ellen (noise pollution):
  → Solution A: Ellen pays Mark to get rid of the dog
  → Solution B: Mark pays Ellen to let him keep the dog
- Problem: private solutions do not work most of the time:
  → Assumption of free transaction cost (cost occur in the process of bargaining)
  → Various interest groups might be involved (coordination problem)

When no private solutions can be reached, governments need to interfere:

- Command and control policies: regulate behavior directly (e.g. laws, regulations, standards)
- Market-based policies: Provide incentives so that private entities will choose to solve the problem on their own

27.7 Policy options

27.7.1 Economic efficiency

- Economic efficiency is defined as the maximization of social welfare: An efficient market is one that allows society to maximize the net present value (NPV) of benefits
- Aka Pareto optimal: state of resource allocation in which it is not possible to make any individual better off without making at least one individual worse off

27.7.2 Cost-effectiveness

- A policy is cost-effective if it meets a given goal at least cost (minimizing abatement cost)
- Cost-effectiveness does not evaluate whether that goal has been set appropriately to maximize economic efficiency

28 Strategies of environmental economics

28.1 Economic / Environmental indicators

28.1.1 Genuine progress indicator (GPI) / Gross domestic product (GDP)

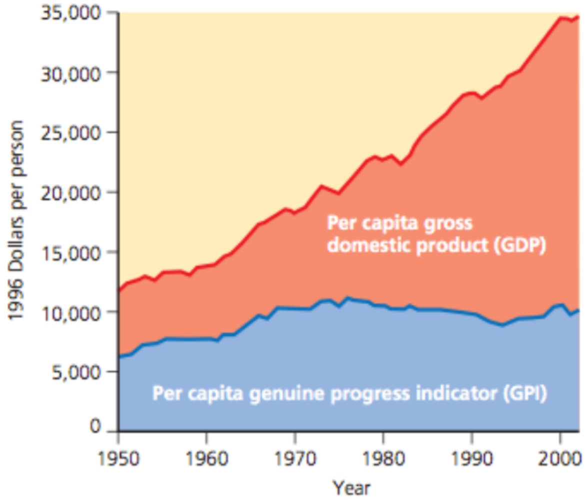
GDP

- Measures the annual economic value of all goods and services produced within a country
- GDP does not distinguish between goods and services that are environmentally beneficial or harmful

New indicators are required, which also monitor environmental quality and human well-being

GPI

- Estimated harmful environmental costs (e.g. pollution, resource depletion, degradation) and social costs (such as crime) are subtracted from GDP



28.1.2 Happy planet index (HPI)

Instead of using GDP, the success of a country is calculated by:

$$\text{HPI} = \frac{(\text{country's life satisfaction index}) \cdot (\text{average life expectancy})}{\text{ecological footprint}}$$

28.1.3 Gross national happiness (GNH)

GNH is a measure of a countrys efforts toward sustainable economic development based on:
Conservation of natural environment, Preservation of cultural values, Economic equity, Good governance.

28.2 Full-cost pricing

- Full-cost pricing refers to prices including internal costs + external costs (externalities)
- Full-cost pricing would reduce resource waste, pollution and environmental degradation
- Improves human health by encouraging producers to invent more resource-efficient and less-polluting methods of production
- Would allow consumers to make more informed choices
- Jobs and profits would be lost in environmentally harmful businesses as consumers chose green products
- Jobs and profits would be created in environmentally beneficial businesses

28.2.1 Implementation barriers

- Producers of harmful and wasteful products oppose such pricing
- Estimation of environmental and health costs have high uncertainties involved

- Most consumers do not connect harmful costs with certain goods and services: requires consumer education and eco-labeling
- Full-cost pricing requires strict government action

28.3 Monetary value of natural capital

Different ways exist to estimate monetary values of natural capital/pollution.

28.3.1 Mitigation cost

- How much would it cost to move an endangered species to a new habitat?
- How much would it cost to clean up soil contaminated by acid rain?

28.3.2 Willingness to pay

- How much would people pay to maintain a certain forest or to keep a certain species?
- How much would you pay to have an uncontaminated soil field?

28.4 Discount rate

- Estimate of a resources future economic value compared to its present value
  → Having something today may be worth more than it will be in the future
- Discount rate is a primary factor how resources (e.g. forests, rivers) are used
- 0% discount rate means that a forest worth 1 million Euro today will still be worth 1 million Euro in 50 years
- Today many business and organizations (e.g. World Bank) use 10% annual discount rate:
  - → Forest would be worth much less in 50 years
  - → Cuhng down forest as quick as possible makes the most economic sense
  - → Does not take into account economic value of ecological services provided by the forest
- Process of choosing a discount rate is controversial
  - → High discount rates encourage rapid exploitation of resources for immediate payoffs
  - → 0% or even negative discount rates would make use of non-renewable and renewable resources more sustainable

28.5 Cost-benefit analysis

- Tool for making economic decisions about pollution control and resources management
- Comparison of estimated costs and benefits for a certain action (e.g. implementing a pollution control regulation)
- Direct costs like land, labor, materials or pollution-control technologies are easy to estimate
- Indirect costs (e.g. clean air, biodiversity) are more difficult to estimate
  → Depend on individual assumptions, value judgments and discount factors
- Cost-benefit projects potential outcomes
- Cost-benefit evaluates alternative actions

28.6 Phase out of environmentally harmful subsidies / tax breaks

TODO

28.7 Establish laws and regulations to prevent pollution and resource degradation

28.7.1 Environmental regulations (prescriptive regulations)

28.7.2 Technology standard

28.7.3 Performance-based standard

28.8 Increase/establish taxes on pollution, resource waste and environmentally harmful goods and services

28.8.1 Market-oriented approaches (aka market-based approaches)

28.8.2 Emission taxes

28.8.3 Emission taxes (aka Green taxes or Pigovian taxes)

28.8.4 Green taxes

- Companies will only decrease pollution when the incentive is profitable
- Cost of reducing an additional unit of emissions → Marginal abatement cost (MAC)
- MAC increases as the emission reduction amount increases

  → Measures with lowest cost to reduce emissions are implemented first

  → Additional reductions require more costly measures

TODO