Causes of environmental problems

Basic terms

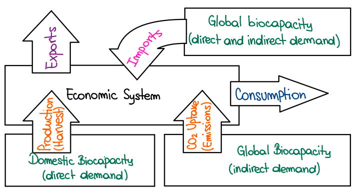
- Environment: the surrounding and physical, chemical, and biological factors affecting living organisms.
- Ecology: the study of how organisms interact with each other and with their environment.
- Ecosystem: a community of living organisms interacting with each others, non-living components, and energy.
- Natural capital: natural resources and ecosystem services that support life, provided mainly by nature & solar energy.

Environmental impact

- Ecological footprint: the amount of biologically productive land and water needed to provide resources & absorb waste.
- Ecological deficit: occurs when ecological footprint exceeds nature's capacity to regenerate resources & absorb waste.
- Per capita ecological footprint: the average amount of Earth's resources consumed by one person.

Ecological footprint calculation

$$EF_C = EF_P + EF_I + EF_E$$



Sensitivity analysis

sensitivity of a single parameter & how much it impacts.

Scenario analysis

optimization of multiple parameters to minimize the impact.

Pollution: harmful matter or energy released into the env.

Sources

- Point source: clear single source (eg. factory pipe).
- Nonpoint source: spread-out source (eg. fertilizer runoff).

Pollutants

- Biodegradable: naturally broken down.
- Non-degradable: persist in the environment.

Best solution: prevention is better than clean-up because it avoids pollution at the source.

Environmental problems

Causes: population growth, poverty, unsustainable resource use, exclusion of env. costs, insufficient knowledge about nature.

Ecosystem

Carrying capacity in general systems

The maximum level of output or performance that a system can sustain over time without experiencing degradation or failure.

Carrying capacity in population

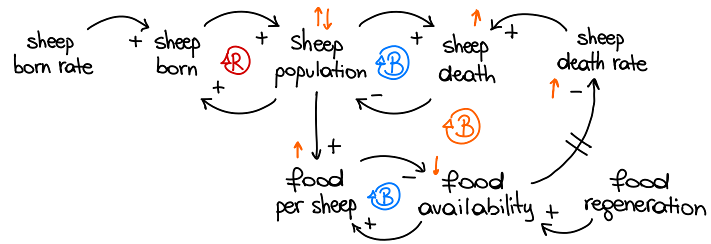
Maximum population size of a species that an environment can sustain indefinitely, given the available resources and environmental conditions.

System characteristics

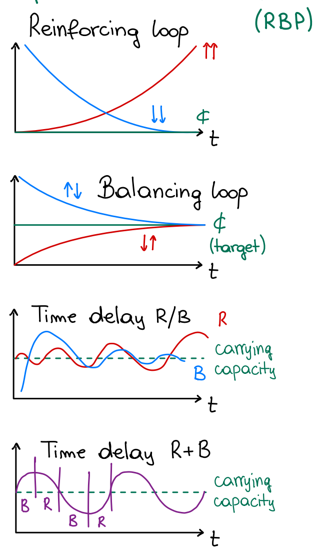
1) Input and Output ; 2) Set of components ;
3) Rules & relationships between components;
4) System's boundaries

Causal Loop Diagram

Sheep pop. in Tasmania



Reference Behavior Pattern (RBP)



Stock & Flow Diagram (SFD)

Elements: Stock, Flows, Converters, Connectors, Sources, Sinks

Stocks

- Part of a system whose value at any given instant in time depends on the systems past behavior.
- $S(t) = \int_{t_0}^{t_1} (\text{inflows} - \text{outflows})\, dt + S(0)$
- Stocks represent anything that accumulates, and are only affected by inflows and outflows.
- They can be tangible or non-physical (eg. level of fear), and are usually named with a noun.

Flows

- Represent activities that lead to in/outflows to stocks (eg. births, migration)
- Are usually presented by verbs or an action

Converters

- Contain equations that generate an output value during each time interval of a simulation (eg. birth rate)
- Can be used for storing constant values (eg. initial pop. size)

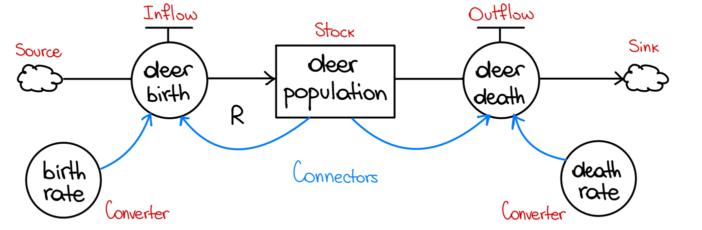
Connectors

- Transmit info to regulate flows
- Can connect into flows. Cannot connect into stocks!

Sources and Sinks

- Are stocks that lie outside the system boundary
- Show stock in/outflows that enter/leave the SB (eg. immigration/emigration)

SFB – Deer population



Biodiversity

Is the variety of life at species, genetic, ecosystem, and process level.

- Provides food, materials, energy, and medicines
- Supports air & water quality; increases ecosystem stability

Species diversity

- Species richness: number of different species an ecosystem contains.
- Species evenness: relative abundance of individuals in each species.

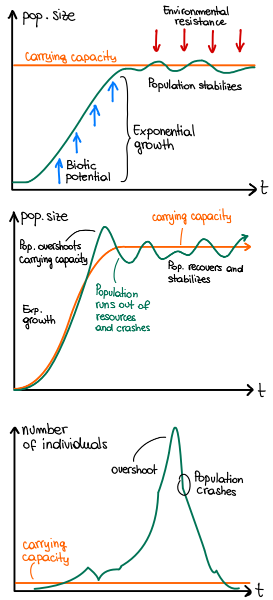
↳ Higher species richness usually increases ecosystem productivity & sustainability.

↳ Natural extinction is normal, but human activity accelerates premature species loss.

Population dynamics

- Population: individuals of the same species living in the same place at the same time.
- Population change = (births + immigration) − (deaths + emigrations)
- Pop. factors: distribution, size, age structure, density.
- Pop. size: births, deaths, immigration, emigration.
- Intrinsic growth rate: maximum growth rate under real conditions.
- Environmental resistance: factors that limit pop. growth (eg. limited resources, competition).

Growth patterns



Human influence

- Lost of species may provide unknown ecological or economic value
- Biodiversity supports natural capital
- Extinction reduces ecosystem stability

Instrumental value

Species are useful for goods and services, ecological functions, recreation, scientific knowledge.

Climate

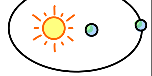
Weather: short-term local atmospheric conditions (temp, rain, RH, clouds, wind, ...).

Climate: regional long-term avg. weather patterns.

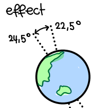
Natural factors & cycles

Milankovitch cycle – 3 theories

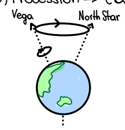
1) Eccentricity → Earth's orbit changes shape: circular ↔ elliptical (± 100'000 y). The more elliptical, the less time the Earth spends near the Sun. Less solar energy → cooling effect



2) Obliquity → Angle of tilt of the Earths axis changes (± 41'000 y). Land mass of the northern emisphere faces more/less towards the Sun → Cooling/Warming effects.



3) Precession → Earth's axis changes direction (± 26'000 y).



It causes winters and summers to be warmer or cooler, depending on the amount of land surface being more or less exposed to the Sun irradiation.

⇒ These cycles combined cause interglacial periods (± 100'000 y).

Oscillations: irregular ocean-atmosphere cycles (months to decades)

↳ shift rainfall, temp, winds, storm patterns.

Sunspots: dark magnetic areas on the Sun

more sunspots → slightly more solar radiation → possible warming

ENSO: Pacific Ocean oscillations with El Niño & La Niña phases → strongly changed global weather, El N. raises global temps.

Volcanoes: eruptions release ash + sulphur gases into the upper atmosphere → aerosols reflect sunlight → short-term global cooling

Albedo: reflectivity of Earth's surface. Snow/ice = high albedo; water/land = lower albedo. lower albedo → more heat absorbed → warming.

Anthropogenic factors

Greenhouse effect

- Natural GHE keeps the Earth warm enough for life
- Enhanced GHE: human activities increase CO_2, CH_4, N_2O
- Main causes: fossil fuels burning, agriculture, deforestation, landfills.
- $CO_2 = 1\,CO_2e$; $CH_4 = 16\text{–}26\,CO_2e$; $N_2O = 280\,CO_2e$

Limits

CO_2: 280 ppm pre-industrial → 399 ppm in 2014

Limit = 450 ppm, Target = 350 ppm

Prevention

Reduce fossil fuel use, deforestation, intensive agriculture, landfill emissions, nitrogen fertilizer use.

GWP(100)

- Measures how much heat a GHG traps compared to CO_2 over 100 years.
- Depends on heat absorption strength & residence time (atm)

Projected effects of Global Warming

At +2°C: More heat waves, droughts, fires, glacier melt, coral bleaching, and sea-level rise.

At +3°C: Water shortages, crop losses, disease spread, coral reef collapse, and more extinction.

At +4°C: Severe water scarcity, food insecurity, ecosystem collapse, faster sea-level rise, mass extinction risk.

Impact on biodiversity

- +1,5 – 2,5 °C: ~30% of land species at risk.
- >3,5 °C, up to 70% at risk.
- Disrupts migration, food availability, & ecosystems.
- High extinction risk, especially in cold regions.

Impact on humans nutrition

- Crop yields may increase in some temperate regions.
- Crop yields decrease in tropical/subtropical regions.
- Droughts and floods reduce food production.
- 200 - 600 million people may face malnutrition.

Impact on humans health

- More heat-related deaths.
- Wider spread of diseases like malaria & dengue.
- More air pollution and urban smog.

Reducing GHG emissions

Improve energy efficiency, shift from fossil fuels to renewable energy, stop deforestation, reduce land clearing, use CO_2 capture and storage, consider geo-engineering.

Energy systems

Energy use & wealth

- Wealth measured by GDP → higher GDP per capita means higher energy use per capita
- PPP (purchasing power parity) adjust GDP (sum of all goods and services produced in a country per year) for different purchasing power between countries.

Quality criteria: reliable supply, always available, low price.

Goals

Physical goals: ensure reliable, efficient, safe energy supply.

Financial goals: reduce costs, maximize profit in commercial sys.

Env. goals: reduce GHG emissions and air pollution, limit resource extraction impacts, protect water, land, habitats, surroundings.

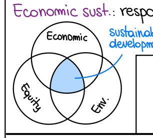
Energy options: use energy more efficiently, improve end-use technologies (eg. insulation), improve convertion technologies (eg. efficient furnaces), replace fossil fuels with renewables.

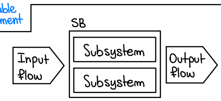
Overall sustainability objectives

Env. sustainability: protection of the env.

Social/Cultural sust.: increasing equity - decrease poverty.

Economic sust.: responsible economic development.





Analytical tools for energy systems

EROI (Energy return on investment)

It measures how much usable energy is obtained to the energy spent to produce it:

$$EROI = \frac{\text{energy delivered}}{\text{energy used to obtain it}}$$

EROI upstream: everything before the operational phase.

" downstream: energy or money used to dismantle/end it.

EPBT (Energy payback time)

It measures how long a technology needs to generate the energy used to produce, install, operate, and dispose of it.

$$EPBT = \frac{\text{cumulative energy demand}}{\text{yearly net energy generated}} = \frac{E_{material} + E_{manufacturing} + E_{installation} + E_{disposal/recycle}}{E_{generated} - E_{operation\ \&\ maintenance}}$$

Kaya equation

It is used to analyse total CO_2 emissions (country/globally).

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

P = pop. ; $\frac{GDP}{P}$ = wealth / person ; $\frac{E}{GDP}$ = energy intensity of the economics ; $\frac{CO_2}{E}$ = carbon intensity of energy

To reduce CO_2

Improve E efficiency: $\downarrow \frac{E}{GDP}$; Use low-carbon E: $\downarrow \frac{CO_2}{E}$

Life cycle assessment (LCA)

LCA phases (ISO 14040, 14044)

1) Goal and scope definition

- Goal defines why the LCA is done.
- Scope defines how large/deep the study is: Sys function, SB, assumptions/limitations, data requirements, LCIA, functional unit ↳ cradle to cradle (extraction to disposal) to grave (extraction to recycling/reuse)

2) Life Cycle Inventory (LCI)

- LCI collect and quantifies all system inputs & outputs, providing the data basis for measuring env. impacts in an LCA.
- Includes: raw materials, energy use, water use, emissions to air, water, land.
- LCA stages: resource extraction, transport, manufacturing/conversion, use phase, maintenance, disposal/recycling.

3) Life cicle impact assessment (LCIA)

- It evaluates the magnitude & significance of potential env. impacts.
- Steps: select impact categories; calculate impact potential; if necessary, normalize and weight impacts.
- Impact categories: climate change, acidification, smog formation, ozone depletion, eutrophication, toxicity.

4) Interpretation → Eco-indicator 99

It assesses env. damage in 3 categories: Unit ↓

1) Human heath: yrs. of life lost + yrs. lived w/ disability [DALYs].
2) Ecosystem equality: loss of biodiversity over area & time [species loss].
3) Resources: extra future E needed to extract low-quality resources [Surplus E].

Damage models

- High-quality resources are used first → Future extraction: ⇈ En.
- Land use degrades habitants and reduces species diversity.

Human health emissions (on a scale, eg. locally or globally)

1) Fate: where pollutants go and how long they stay.
2) Exposure: how much organisms take in.
3) Effect: predicted diseases or damage.
4) Damage: final impact expressed [DALY for humans, else %].

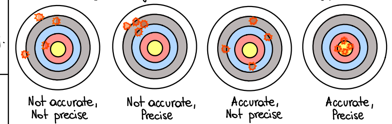
LCA modelling terminology

Product: what serves the process (eg. plastic, metal, crude oil, ...). The raw, virgin material is always a product.

Process: it creates the product. Whenever a product is transported, refined, modelled, molded, ...

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

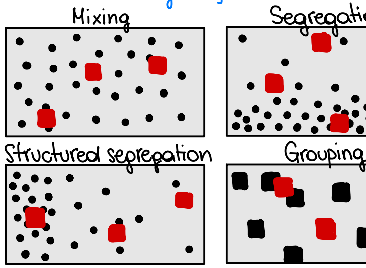
Accuracy: describes how close a measurement is to the true or accepted value. It is only meaningful when the result is also sufficiently precise.



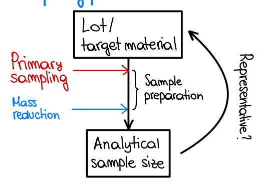
Representative Sampling for environmental QCQA

QCQA = Qualitative Control and Quality Assurance

Material heterogeneity



Sampling process



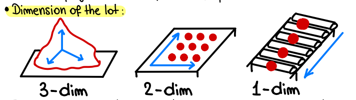
■ = arbitrary pick of a sample
● = position of the matter

Theory of Sampling (TOS)

TOS = 6 general principles + 4 Sampling Unit Operations

TOS terminology

- Lot / Sampling target / Decision unit: the complete material or entity selected for sampling (eg. truck load, ship cargo, bags). Includes physical size/shape, mat. properties, Sampl. boundaries.
- Dimension of the lot:



- 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.
- Fragment: the smallest separable unit of the lot that is not affected by the sampling process itself (eg. particles, molecules, grains).
- Representative sample: must be based on correctly delineated & materialized unit of the lot, as well on combination of increments. A sample can only be representative if the sampling process is both accurate and precise / reproducible. Sampling bias ≠ analytical bias.
- Analyte: specific identified / measured substance in a sample.

General principles (GPs)

Fundamental Sampling Principle (FSP)

Every part of the lot must have the same non-zero chance of being sampled ⇒ physical acces to the whole lot.

Lot Dimensionality Transformation (LDT)

Reduce lot dimension and complexity to make sampling easier: eg. 3D stockpile → 1D falling stream → slice → 0D increment.

Principle of Sampling Correctness (PSC) [bias-free sampling]

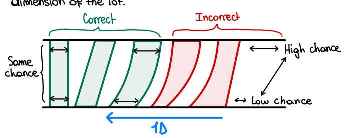
A representative sample must be both accurate & precise.
- Global Estimation Error (GEE)
- Total Analytical Error (eg. ±5%) (TAE)
- Total Sampling Error (TSE)

Sampling errors (still PSC)

Incorrect sampling errors → create bias, must be eliminated.

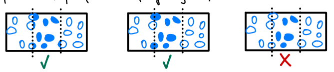
Increment Delimitation Error (IDE)

- Relates to physical extraction of the increments.
- Can be avoided by delineating an increment which covers the relevant dimension of the lot.



Increment Extraction Error (IEE)

It occurs when particles inside the delineated increment do not end up in the sample (center-of-gravity rule).



Increment Preparation Error (IPE)

Arises when increments/samples are altered after extraction (eg. contamination, evaporation, moisture, spillage, sabotage).

Correct sampling errors → errors from heterogeneity.
- Fundamental Sampling Error (FSE).
- Grouping and Segregation Error (GSE).

Heterogeneity

- Constitutional heterogeneity: difference between particles.
  ↳ reduced by crushing
- Distributional heterogeneity: uneven spatial distribution.
  ↳ reduced by mixing and composite sampling.

Sampling Scale Invariance (SSI)

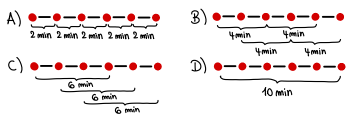
All principles need to be followed regardless lot/increment size.

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

Sampling is never one-shot, but always a multistage process.

Lot Heterogeneity Characterization (LHC)

An appropriate sampling procedure can only be designed knowing the lot heterogeneity qualitatively.
- 3D lots: a replication test will reveal TSE + variance.
- 1D lots: Complete empirical sampling error estimation
  ↳ Variographic analysis:



Sampling Unit Operations (SUOs)

SUO 1) Composite Sampling
Collect many increments to reduce grouping / segregation effects.

SUO 2) Mixing / blending
Homogenize the material to reduce spatial segregation.

SUO 3) Comminution / crushing
Reduce particle size to lower foundamental sampling error.

SUO 4) Mass reduction / sub-sampling
Reduce sample mass while keeping it representative.

Multi-criteria decision analysis (MCA / MCDA)

It compares alternatives using several criteria to support decisions.
Inputs: data, risk analysis, cost analysis, stakeholder analys.
Possible criteria: GHG emissions, air/water pollution, EROI, economic value, social impacts.

Steps of MCDA

1) Define aim and scope of analysis.
2) Selection of decision criteria and weight scale.
3) Calculation of scores for each criterion.
4) If weight scale is modified → recalculation of criteria weights.
5) Interpretation of results and sensitivity analysis.

MCDA structure

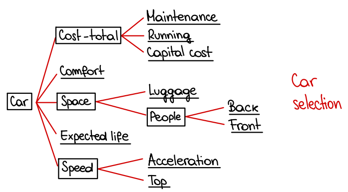
1) Problem identification

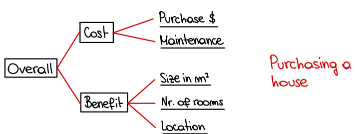
Define the problem, stakeholders, alternatives, decision context.

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 to compare?
- Are alternatives already known or is further research required?
- What is the pre-conceived judgement of the problem?

2) Problem structuring

Define alternatives and criteria → value tree. Avoid overlapping criteria.





Focussing questions:
- Which are the alternatives? Do unknown alternatives exist?
- Do certain alternatives overlap? If yes, can they be grouped?
- Which criteria exist to evaluate the alternatives' differences?
- Are these criteria pre-emptive? If yes, which alt. can be screened out?
- What is the logical hierarchical structure of the criteria?

3) Assessment

Assign numerical scores to alternatives and criteria.

Scales
- Ordinal: ranking only; differences are not measured.
  eg. dissatisfied → satisfied; bad → good.
- Interval: equal differences, but not true zero.
  eg. temperature in °C → $\Delta T_1 = (15-10)K$, $\Delta T_2 = (5-0)K$, $\Delta T_1 = \Delta T_2$
- Ratio: equal differences + true zero.
  eq. cost, mass, energy use, amount of money in my wallet.

Scale choice: depends on whether data is qualitative or quantitat.

Linear vs. non-linear scale
Preference does not always increase linearly.
eg. the best house size may be medium, not the largest.

Focussing questions:
- What data is available and what is its quality?
- Do some criteria require qualitative scoring?
- Do certain criteria require non-linear scales?
- How can numerical values (with different units) be converted 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.

4) Sensitivity analysis

Check how results change if weights or assumptions change.

5) Decision / planning

Use MCDA results to support the final decision / future plans.

MCDA calculations - example

Data

	Hydro	Wind	Nuclear	Natural gas
ENVIRONMENT	α	β	γ	δ
CO_2 eq.	4	10	10	423
Land use	92	28	7	47
Fatalities in an accident	3e-3	1e-4	2e-2	1e-2
Waste mass	14	12	24	18

Normalized indicator values and weighting

	Weighting Factors Level 1 A	Weighting Factors Level 2 B	Weighting Factors Level 3 C	Weight on indicator level
ENVIRONMENT	33,3%	100%		D = C·A/B
CO_2 eq.			45%	15%
Land use			30%	10%
Fatalities			10%	3%
Waste mass			15%	5%

Weight on indicator level D	Hydro	Wind	Nuclear	Natural gas
D = C·A/B	α	β	γ	δ
15%	E			
10%				
3%			F	
5%				
Sustainability score of ENVIRONMENT:	Σα	Σβ	Σγ	Σδ

$$E = \left(1 - \frac{\alpha - \max(\alpha,\beta,\gamma,\delta)}{\max(\alpha,\beta,\gamma,\delta) - \min(\alpha,\beta,\gamma,\delta)}\right)\cdot 100$$

$$F = \left(1 - \frac{\gamma - \max(\alpha,\beta,\gamma,\delta)}{\max(\alpha,\beta,\gamma,\delta) - \min(\alpha,\beta,\gamma,\delta)}\right)\cdot 100$$

Ecosystem Services (ES)

Benefits humans obtain from ecosystems, directly or indirectly.
Ecosys. services link biodiversity, ecosyst. functions, human well-being.
- Shows economic and social value of nature.
- Supports biodiversity conservation
- Explains why ecosystem loss affects humans.

Ecosystem

A dynamic system of living organisms and non-living environment interacting as one functional unit.
- Organisms interact through competition, predation, parasitism, ...
- Ecosystem boundaries depend on strong internal interactions and weaker external ones.
- Ecosystems can exist at any scale, from a small pond to an ocean.
- Humans are part of ecosystems and depend on them for survival.

Human wellbeing

Depends on basic needs, health, security, social relations, and freedom of choice. Well-managed ecosystems reduce vulnerability. Degraded ecosystems mainly harm poorer / rural populations.

ES classification

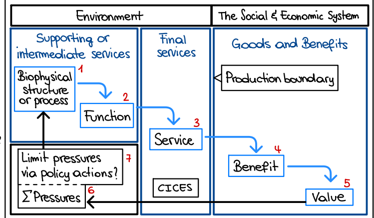
Provisional services: material or energy outputs for ecosystem. eg: food, freshwater, timber, fibres, fuel, general resources.
Regulating services: benefits from ecosystem processes that regulate env. conditions. eg: climate regulation, flood control, disease control, water purification, air quality regulation, erosion control.
Cultural services: non-material benefits linked to human values and experiences. eg: recreation, tourism, cultural identity.
Supporting services: basic ecological processes needed for all other services. eg: soil formation, nutrient cycling, primary production.
CICES: Section → Division → Group → Class → Class type

Key characteristics of ES

Public-private good spectrum
- Private or market goods: both rival and excludable.
- Toll or club goods: non-rival, but excludable.
- Open access or common pool resources: rival, but non-excludable.
- Pure-public goods: neither rival nor excludable.

Spatial / temporal dynamism: services and benefits may occur in different places or times. eg: water regulation → provision: mountain; benefit: downslope
Joint production: one ecosystem can provide many services at once.
Complexity: ecosystems have feedbacks, thresholds, and time lags.
Benefit dependance: what counts as a service depends on the benefit / stakeholder considered.
Substitutes: some ES can be replaced by technology (often high costs).

Cascade model



Example with edification of Horw wetland w.r.t Horw municipality
1) Swamp; 2) Habitat for biodiversity; 3) Flora + fauna conservation; 4) Place for relaxing, walk, contact with nature; 5) Willingness for the municipality to pay for the preservation of biodiv; 6) Space for commercial use; 7) Environmental protection.

Alternative approach

ES concept benefits

Integrate nature into decision-making; Make ecosystem benefits visible and measurable; Supports protection, restoration, & enhancement; often creates multiple benefits at once for people.

ES concept challenges

Uncertainty: ES are hard to measure across scales and time. Services are often bundled and hard to separate.
Complexity: ES interact with each other. Effects depends on: boundaries, scale, habitat heterogeneity. Local benefits may cause wider negative impacts.
Ethical issues: Some ES should not be privately owned. Non-rival services should be managed cooperatively.
Market failure: many ES have no market price. Markets often ignore cultural & regulating services.
Conceptual limits: ES may not represent all cultural values of nature.

Value in ES

- Value: criteria people use to assign importance to nature / things.
- Can be individual / collective and qualitative / quantitative.

Value pluralism & incommensurability
- Value plur.: nature can have different, sometime conflicting values.
- Incomm.: not all values can be reduced to one indicator (eg. money).

Human-nature relationships
- Gaining from nature: nature as provider of benefits.
- Living for nature: nature has value beyond human use.
- Living in nature: humans are part of nature and depend on it.

Value types

Intrinsic value: nature has value in itself, independent of human use.
Ecological / Biophysical: importance of species, processes, and ecosystem functions for ecological integrity.
Instrumental: nature has value as a mean to achieve human goals.
Economic: value measured via use / non-use benefits, often using WTP/WTA.
Relational: Value from relationships between people, nature, places, identities.
Shared: values held collectivity by groups or societies.

Pluralistic valuation

Diverse values of nature's contribution to people (NCP)

1) Purpose
- Define why valuation is done
- Context: decision-making, awareness, litigation, conflict resolution.

2) Scoping
- Set valuation boundaries and choose suitable methods.
- Decide: whose worldviews are included; which values are relevant; which spatial, temporal, social scales matter; how stakeholders express values.

3) Pluralistic valuation
- Use different methods for different value types.
- Combine biophysical, economic, health-based, cultural, local perspectives.
- Acknowledge trade-off, power relations, incommensurable values.

4) Integration and Bridging
- Integrated modelling, MCDA, narrative analysis, deliberative valut.

5) Communicate on values and review the valuation process
- Share results with public and decision-makers.
- Communicate uncertainty and confidence limits.
- Use stakeholder feedback for adaptive decision-making.

Geographic Information System (GIS)

- GIS: system to collect, manage, analyze, and map spatial data.
- Spatial data: info about location, shape, relationships between features.

GIS components

- Data: maps, databases, remote sensing, statistics.
- Software + hardware
- Methods: define problem → analyze data → verify results.

Main uses

- Env. analysis: habitats, hazards, resources, emissions.
- Planning: infrastructure, population, transport, grids, navigation.

Remote sensing

Active: sensor emits energy (eg. radar / LiDAR).
Passive: sensor detects natural reflected energy (eg. sunlight).

GIS Method

1) State the problem: define the aim.
2) Break it down: identify objectives, needed data, relevant interactions.
3) Analyze input data: find spatial relationships & patterns.
4) Perform analysis: use suitable GIS tool.
5) Verify result: check if assumptions, criteria, or data need adjustment.
6) Implement result: apply the result for planning or decision-making.

GIS data

Raster: Grid cells; good for continuous data (eg. temp., elevation).
Vector: Points, lines, polygons; good for discrete objects (eg. roads, borders).

Non-renewable energy sources

- Cannot be replaced on human time scale. Include fossil fuels + nuclear fuels.
- Fossil main type: coal, oil / petroleum, natural gas.

Energy density

- Is the amount of energy stored per unit of mass or volume.
- Units: Coal [GJ/t]; Oil [GJ/barrel]; Natural gas [MJ/m³].

Reserve vs Resource

Reserve: proven quantity known to exist and economically extractable.
Resource: estimated quantity that may exist but not fully explored or economically extractable.
Reserve exhaustion: prod. increases → reaches the peak → prod. declines due to harder extraction.

Fossil fuels: coal

Ranking of coal

– Heating value & Carbon content → +
+ ← Moisture content –

Peat (Not coal) $\xrightarrow{H+P}$ Lignite (25% - 35% C) $\xrightarrow{\text{Heat + Pressure}}$ Sub-bituminous coal (35% - 45% C) $\xrightarrow{H+P}$ Bituminous coal (45% - 85% C) $\xrightarrow{H+P}$ Anthracite (85% - 97% C)

Extraction techniques

Surface mining: shallow mining, cheaper; removes topsoil/rock only.
Open-pit: large pit for ores/stones; machines dig and remove material.
Strip: removes overburden above horizontal deposits near the surface.
Contour strip: cuts terraces into hillsides, mainly for coal layers.
Underground: deeper mining, expensive, dangerous.
Coal transport: crushed after mining. Railway, truck, conveyor, cargo.

Coal pros & cons

Pros: cheap, abundant; high EROI; reliable electricity production; easy storage / transport; useful by-products (gypsum, fly ash).
Cons: non-renewable; very high CO_2 emissions; SO_2, NO_x, air pollution; acid rain, smog, health impacts; mining / transport cause env. damage.

Air pollution reduction

Preventive measures: choose suitable coal type; coal control quality: carbon, moisture, S, N; drying / milling improves combustion.
Control measures: modern plants can remove >80% NO_x, 90% - 95% SO_x, ~99% of fly ash

Main technologies
Electrostatic precipitator: removes fly ash using charged plates.
FGD / wet scrubber: removes SO_2; limestone / lime slurry → gypsum.
DeNOx: removes NO_x using NH_3, producing N_2 and H_2O.
CCS: captures and stores CO_2 but costly, energy-intensive.

Alternatives
Synfuel: coal can be converted into synthetic gas or liquid fuels, but this needs more coal, emits more CO_2, uses more water, has low net E yield.
Biomass: burned directly into biofuels (bio-diesel, -ethanol, -gas).

Environmental economics

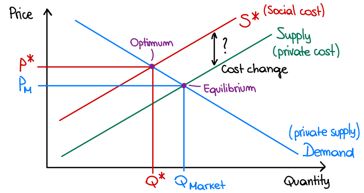
Introduction & definition

Economics: studies production, consumption & distribution of goods + wealth.
Microeconomics: individuals, firms, buyers / sellers.
Macroeconomics: whole economies (eg. national economic activity).
Economic system: system where goods/services are produced, distributed, and consumed. Uses 3 types of capital:
1) Human capital: labour, knowledge, skills.
2) Manufactured capital: machines, factories, infrastructures.
3) Natural capital: resources and ecosystem services from nature.

Free-market system
No government intervention; perfect infos between seller - buyers; prices should include all direct and indirect costs.

Externalities
Negative: harmful effect not paid by the polluter. (eg. pollution affecting downstream communities).
Positive: beneficial effect not fully paid to the provider. (eg. technology spillovers benefiting society.

Market failure
Markets fail when prices do not reflect full social costs / benefits. Env. economics helps correct this through pricing, regulations, incentives.



Coase theorem: if bargaining is cost-free, private parties can solve externalities themselves. Usually unrealistic because: transaction costs exist; stakeholders may be involved; coordination is difficult.
Willingness to pay // Willingness to accept

Policy options

Economic efficiency → "Best goal for society"
- Goal: maximize total social welfare
- Efficient market: maximizes net present value (NPV) of benefits.
- Pareto optimal: no one can be made better off without making someone else worse off.

Cost-effectiveness → "cheapest way to reach a goal"
- Goal: achieve a fixed target at the lowest cost.
- Focuses on minimizing abatement costs. Does not check whether the target itself is socially optimal.

Strategies of environmental economics

Full-cost pricing → Goal: reflect the true cost of goods.
- Price = production cost + environmental / social costs.

Effects: less pollution and waste; cleaner production; better consumer choices.
Barriers: hard to estimate external costs; industry opposition; regulations + eco-labels.

Pricing and incentives
- Remove harmful subsidies / tax breaks that make unsustainable activities cheap.
- Use beneficial subsidies to support cleaner options: pollution prevention, sustainable forestry / agriculture, efficient water use, RET.

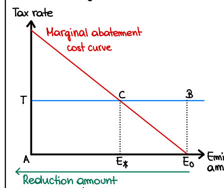
Environmental regulations: government rules to reduce pollution / resource degradation.
Technology standards: require specific technologies / processes.
Performance standards: set emission limits; firms choose how to comply.

Market-oriented approaches
- Do not directly mandate emission rates.
- Use economic incentives to reduce pollution at lowest social cost.
- Main tools: emission taxes / green taxes; marketable permits.

Emission / Green taxes

- Tax charged per unit of pollution emitted.
- Polluters reduce emissions when: MAC = T
  where: MAC = marginal abatement cost; T = tax per emission unit
- If MAC < T: reduce emissions; MAC > T: pay the tax.
- Optimal reduction occurs at E*, where tax equals MAC.

Pros: encourages cleaner technologies; gives firms flexibility to choose cheapest abatement method; easy to administer through tax systems.
Cons: difficult to estimate correct external damage cost; can increase prices and affect low-income groups; may reduce intentional competitiveness; tax revenue may not be used for environmental improvement.



T = tax rate / unit of emission
E_0 = original emission without tax
E_* = emissions after tax applied
C = [MAC = T] point. Equilibrium
B = Tax-rate level at E_0
A = zero-emissions point

Emission reduction = $E_0 - E_*$

If two firms have different MAC curves, reduction should be allocated so that $MAC_A = MAC_B$ → This minimizes total abatement costs.

Tax exercise: given $MAC_1 = 150 - E$, $MAC_2 = 110 - E$:
1) Unregulated emissions
Set MAC = 0 ⇒ $E_1 = 150$, $E_2 = 110$, $E_{TOT} = \sum_i E_i = 260$
2) Tax = 40 €/unit
Set MAC = 40 ⇒ $150 - E_1 = 40 \Rightarrow E_1 = 110$, $110 - E_2 = 40 \Rightarrow E_2 = 70$, $E_{TOT} = 180$
Total reduction: $E_{TOT,0} - E_{TOT,*} = 260 - 180 = 80$
3) Tax = 50 €/unit
$E_1 = 100$, $E_2 = 60$, $E_{TOT} = 160$, Total reduction = 100
4) Tax paid with T = 50
Company 1: $E_1 \cdot T = 100 \cdot 50 = 5000$; Company 2: $E_2 \cdot T = 60 \cdot 50 = 3000$

Marketable Permit System

- Market-based policy for pollution control; government sets a total emission cap.
- Firms receive or buy tradable permits. Firms can: use permits to emit; sell unused permits; buy permits if reduction is too expensive.

Cap-and-Trade
- Sets a limit on total emissions.
- Firms trade permits until their MAC are equals.
- Firms with low MACs reduce more and sell permits; with high MAC buy permits.

Pros: Reduces emissions at lower total cost; encourages pollution prevention; permits price is set by market demand and supply; controls aggregate emission better than command-and-control regulation.
Cons: polluters can continue emitting by buying permits; if the cap is too high, little reduction occurs; monitoring problems can lead to cheating; permit prices can collapse if too many permits are issued.

Permit emissions example: given $MAC_1 = 150 - E_1$, $MAC_2 = 110 - E_2$, cap of permitted emissions: $E_1 + E_2 = 160$.
Equilibrium values: $MAC_1 = MAC_2 \Rightarrow E_2 = 160 - E_1 \Rightarrow E_1 = 100$, $E_2 = 60$.
Permit price: $MAC_1 = 150 - 100 = 50$, $E_2 = 110 - 60 = 50$.
Equilibrium permit price: 50 €/emission unit.

Reducing poverty

- Poverty = inability to meet basic economic needs.
- It worsens: health, environment, resource use, population pressure.
- Its reduction supports: economic development, env. protection, slower pop. growth.

Main solution approaches
- Improve health: reduce malnutrition and infectious diseases.
- Provide education (+ school); stabilize pop. growth (+ women's status).
- Invest in: small-scale energy infrastructure; sustain agriculture.