

CS4800: Designing Sustainable ICT Systems

Lecture 1: Introduction

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Course team

- [Przemysław Pawełczak](#) (course admin and main lecturer)
 - Associate Professor at TU Delft leading <http://github.com/tudssl>
- TA team: Cristian Cuțitei, Alex Despan, Radosław Majer, Alex Nedelcu, Liwia Padowska, Alexandru Postu
- Contact: CS4800-EWI@tudelft.nl (you can try your luck with my personal email, but the odds are against you)

Course made possible by [SIDN Fund](#) support through grant "[Educational ecosystem aimed at sustainable ICT system design](#)"

Learning objectives

1. **List** the methods for assessing ICT industry climate impacts
2. **Comprehend** the implications of different ICT system design decisions on the climate
3. **Apply** ICT system design techniques that minimize climate impact
4. **Analyze** how each ICT system design technique affects climate impact
5. **Create** new methods of ICT system design with sustainability as a core performance metric

Course organization

Lectures

- Thursdays, 15:45-17:30, on campus (check MyTimetable!)
- Each cover one component of sustainable ICT
- Course material: lecture slides + lecture notes (posted after each lecture)

Labs

- Fridays, 15:45-17:30 (check MyTimetable!)
- Project work or online guest lectures
- Assignment description posted today, discussion at end of lecture

Detailed information in official [course repository](#); announcements on Brightspace

Course organization

Week 1.1: Introduction

Week 1.2: Defining Sustainability

Week 1.3: Sustainable Software

Week 1.4: Sustainable Cloud Computing

Week 1.6: Sustainable AI

Week 1.7: Sustainable Electronics Design

Grading and assessment

70% practical assignment

- Group project on **WHAT?!**
- Work in groups of two/three
- Meant to develop deeper understanding of specific topic
- 60% report grade, 10% presentation grade

30% exam

- Multiple choice questions, practice questions available at end of each lecture
- Based on lecture slides + lecture notes
- Meant to test course knowledge

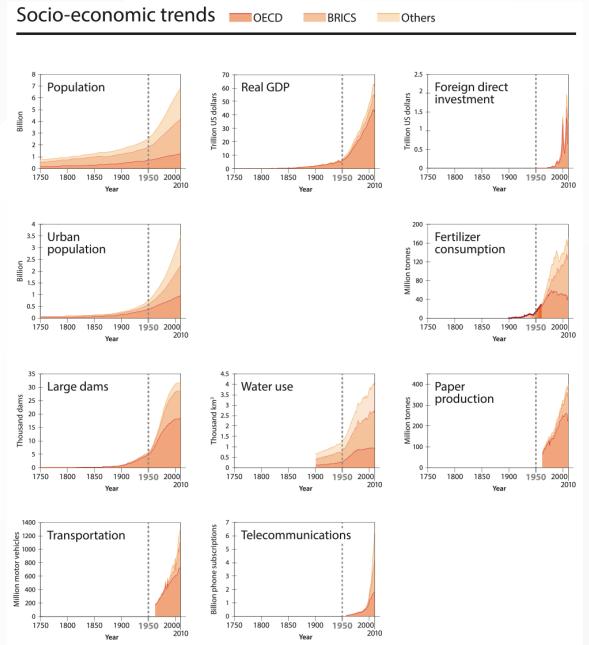
What will you learn in this lecture?

Week 1.1: Introduction

- Basics of climate change
- ICT impacts on the environment
- Prospective solutions
- Economic aspects

"The Great Acceleration"

- Human society has been expanding continuously and exponentially
- Human population, economic development, and technological innovation have grown

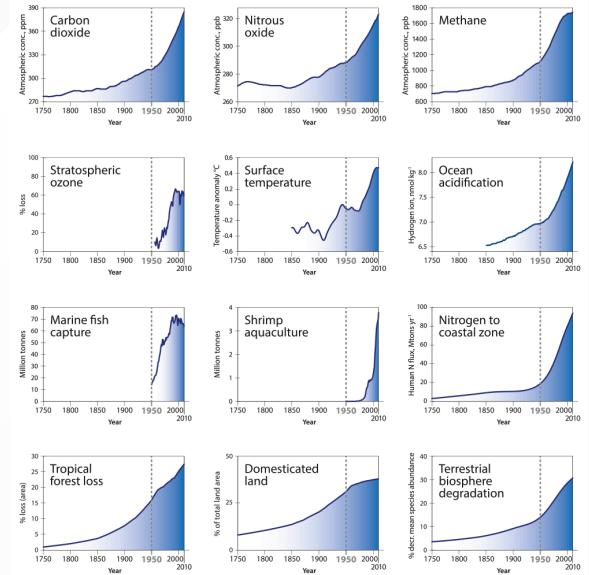


[Historic socio-economic trends](#)

"The Great Acceleration"

- ... but so have environmental impacts of human society on Earth system!

Earth system trends

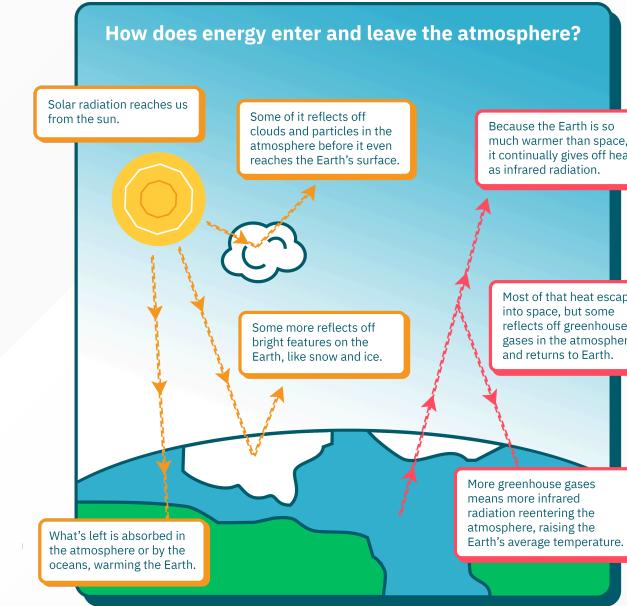


Historic Earth system trends

Climate change

- Earth is in energy equilibrium: incoming solar radiation is equal to infrared energy emitted
- Radiated energy is correlated with Earth's temperature:

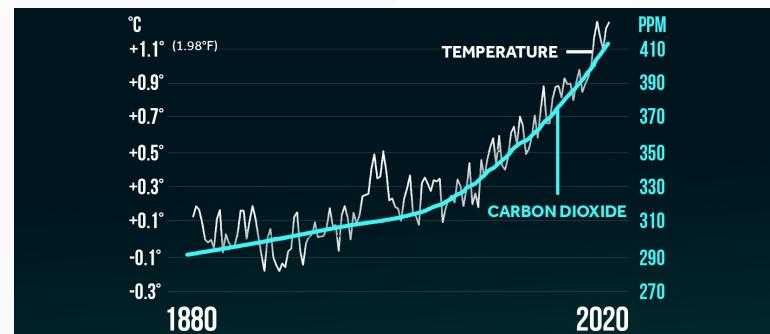
$$\text{infrared radiation} \propto T^4$$



The energy balance within Earth's atmosphere

Climate change: greenhouse gases

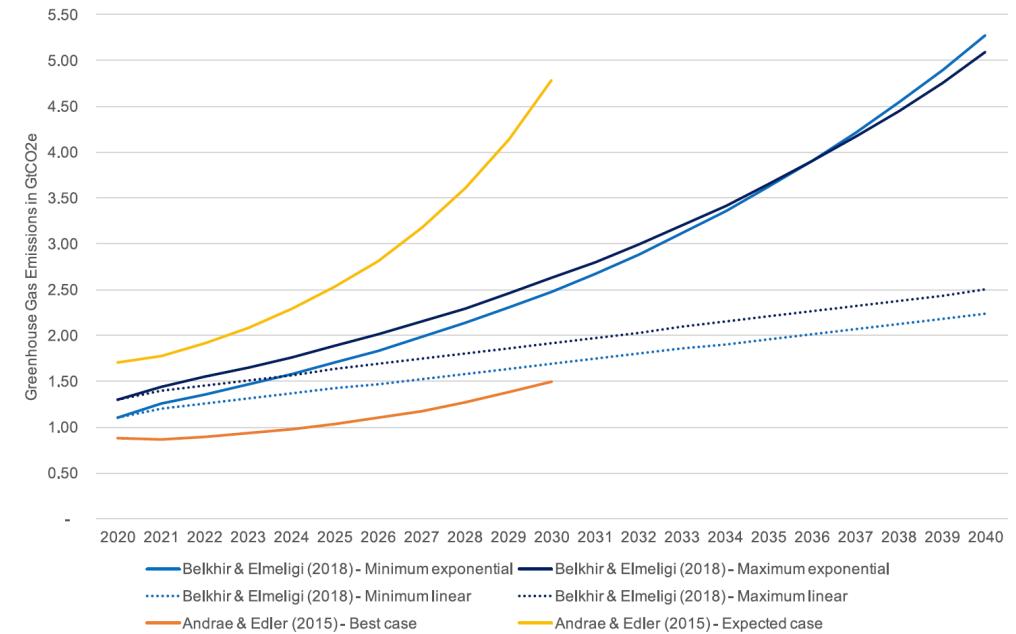
- World economy relies on combustion of fossil fuels
- Greenhouse gases (GHG's) like CO₂, methane are introduced into atmosphere
- GHG's absorb infrared energy emitted by Earth
- Atmosphere heats up to maintain equilibrium → global warming!
- Warmer atmosphere also stores more water → extreme weather patterns!



Correlation between CO₂ concentrations and global temperature

ICT emissions

- Software requires hardware to run it
- Hardware requires energy to run
- Energy production emits GHG's
- Therefore, ICT growth means GHG emissions increase!
- 2020: up to 4% of global emissions, greater than aviation, maritime sector

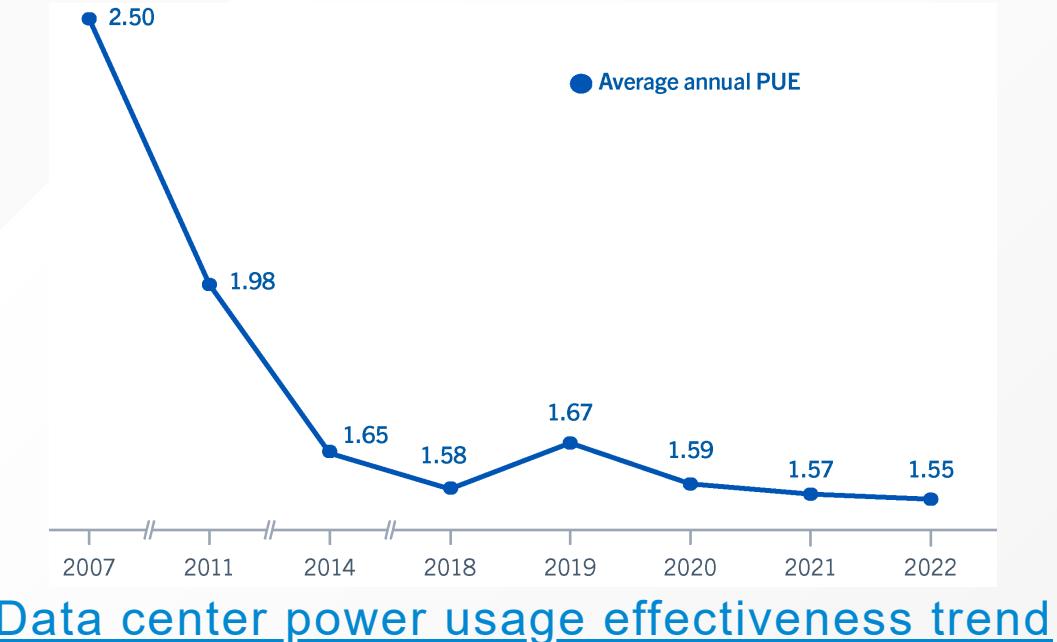


Various estimates for ICT emissions growth

What solutions have been proposed to this problem so far?

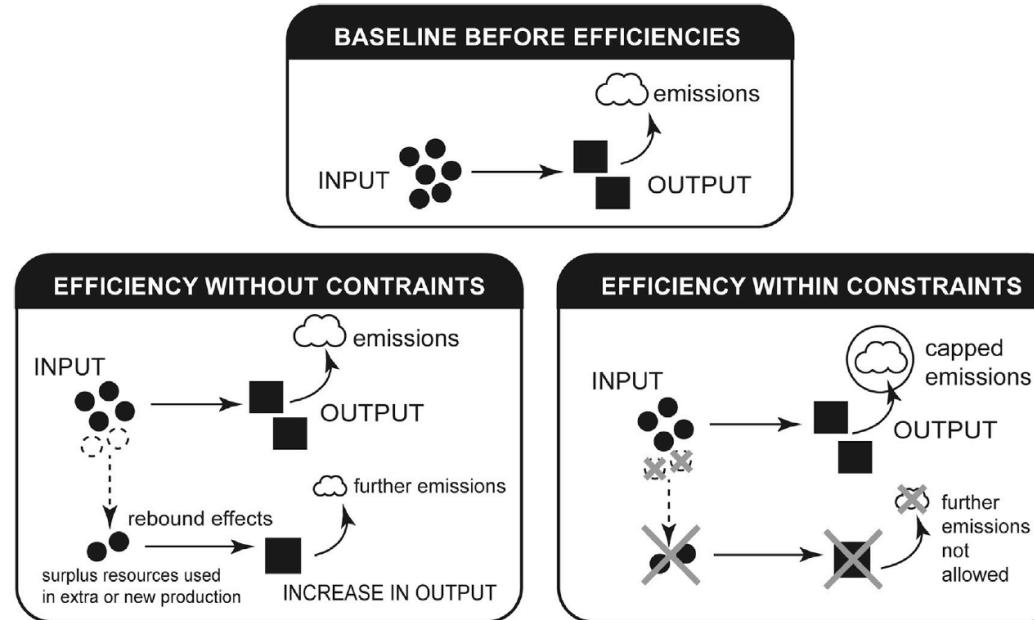
Prospective solutions: improving efficiency

- More efficient ICT systems consume less energy per unit of compute
- Historically: data center workloads increased by 550%, emissions kept stable
- Moore's Law stalling, thermodynamic limits ('quantum entanglement') near
- Efficiency gains slowing



Prospective solutions: rebound effects

1. More efficient process requires less input per output...
 2. Cost per output becomes lower...
 3. ... so more people use it!
- Efficiency improvements eaten up by rebound effects, unless specifically constrained by regulation



Limiting emissions only possible by constraining further consumption from rebound effects

Prospective solutions: saturation

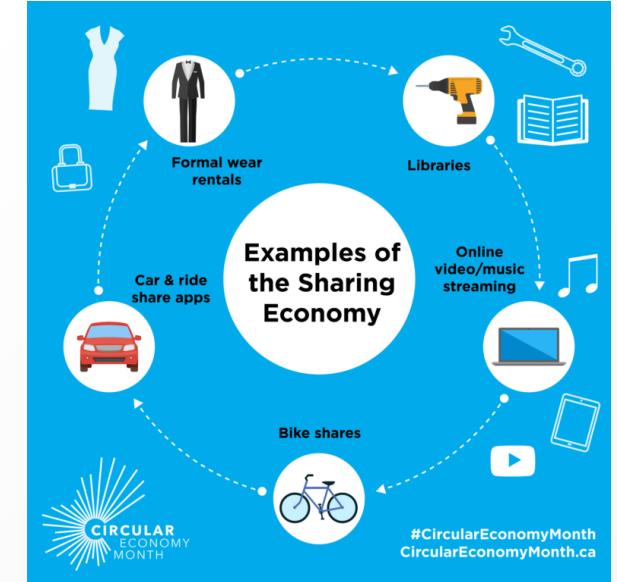
- Once every person on Earth has a smartphone, we should reach a [theoretical cap](#) for emissions
- However, companies keep releasing new products and services
- Saturation is incompatible with how the economy works!



[Planned obsolescence makes saturation unlikely](#)

Prospective solutions: digital sharing

- Industry claims that ICT can help decarbonize other sectors
- Such effects have not yet materialized
- The digital sharing economy might partially help: people use products only when they need them, reducing the amount of products required



Examples of digital sharing

Prospective solutions: carbon removal

- Some form of carbon removal (wetland restoration, ocean capture, enhanced rock weathering) will probably be necessary for 'hard-to-abate' sectors
- Tree planting and other natural methods are insufficient!
- (Still nice to do it)



Planting a few trees can't hurt

Example: carbon capture and storage

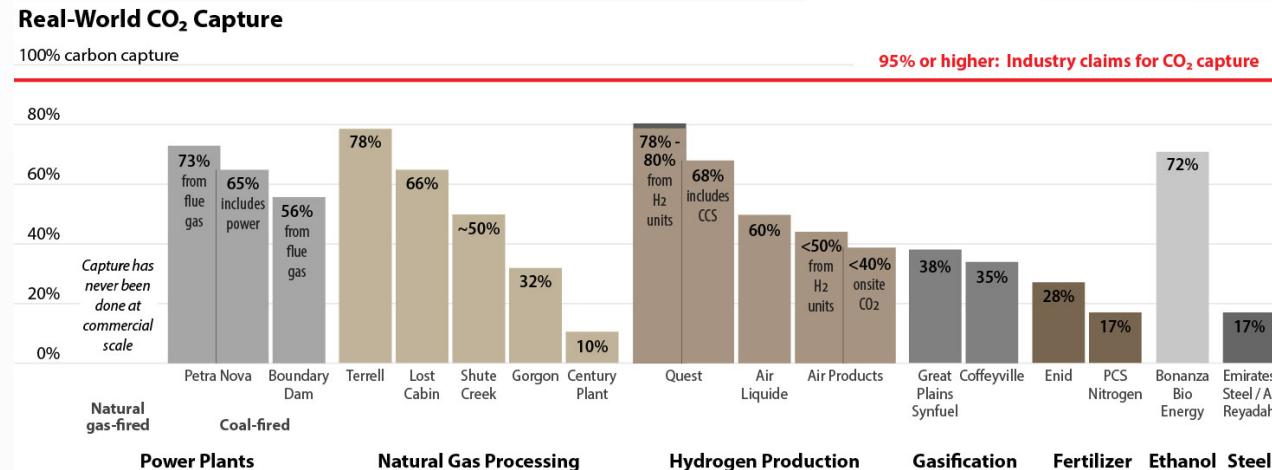
- Industrial carbon capture and storage (CCS) or utilization (CCU): scrubbing of industrial exhaust gas
- Exhaust gas is chemically treated at high temperatures → high energy consumption, needs special chemical solvents
- Resulting CO₂ stream stored or used as feedstock



Industrial CCS facility in Japan

Example: carbon capture and storage

- CCS technology does not work in real life as well as proponents claim
- Requires additional energy, which could be used to directly decarbonize
- We would need enormous amounts of chemicals and energy to capture all global emissions

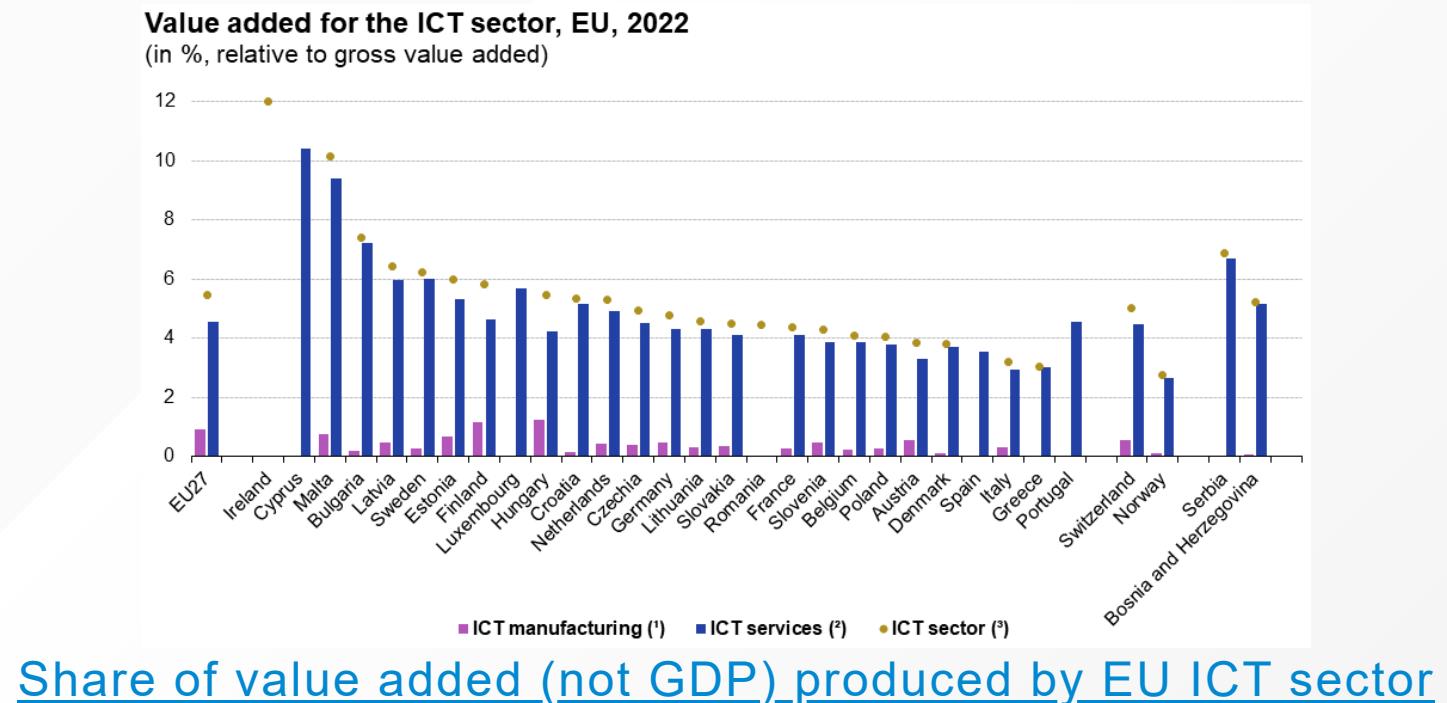


Carbon capture rates in real-world projects vs industry claims

How do we engage with the planet?

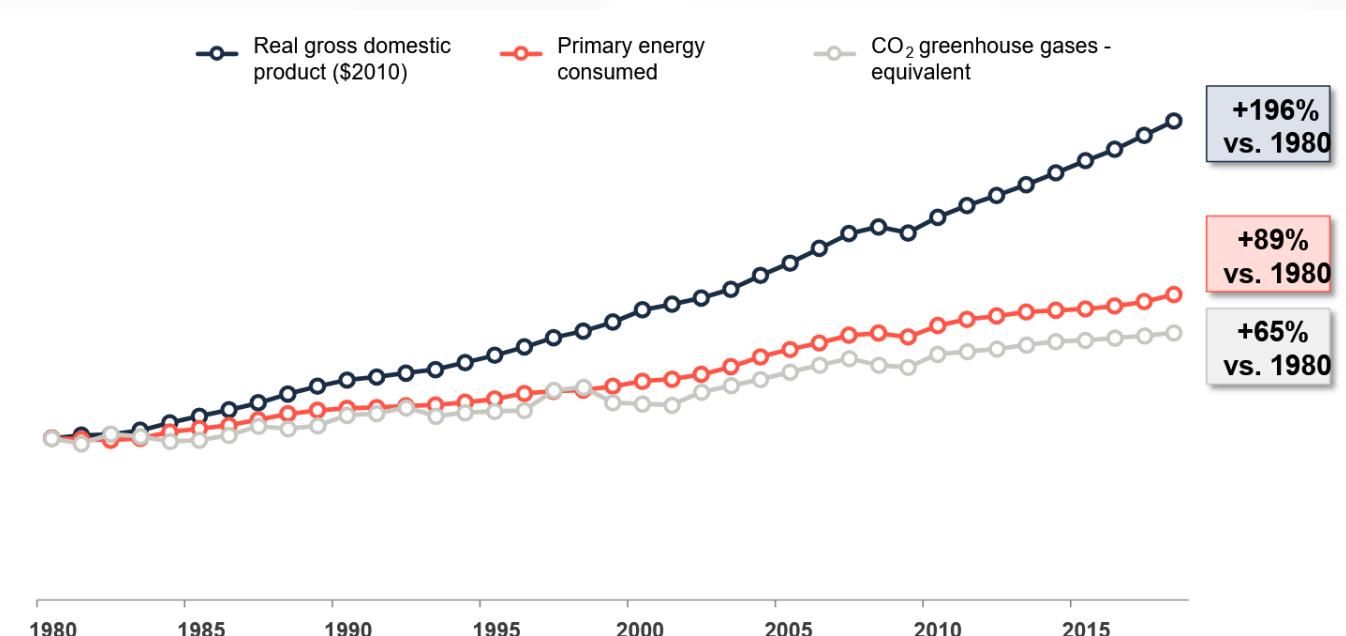
Economics: GDP

- Planet seen as natural capital, extraction produces economic value
- Economic activity measured through Gross Domestic Product (GDP)
- Example: software contribution measured with standard System of National Accounts
- Economic growth traditionally seen as necessary



Economics: energy and emissions coupling

- All economic activity requires energy: [energy-GDP coupling](#).
- Energy currently comes from fossil fuels, so GDP and emissions are also [coupled](#)
- No sustained absolute [decoupling](#) has been observed anywhere!



Economics: growth or degrowth?

- Is it even possible to decouple growth, energy consumption, and emissions?
- Complex economic, political, and philosophical question -> lots of opinions, (respectful) debate invited
- In this course: focus on reducing environmental impacts of ICT systems!
 - Improve software efficiency
 - Study data center design
 - Trade-off costs and benefits of AI
 - Redesign electronics

Recap

- Climate change is caused by combustion of greenhouse gases
- The ICT sector causes a significant part of global emissions
- Proposed solutions are important, but not sufficient to decrease impacts
- Significant future questions about GDP growth and coupling

Exam(ple) questions

- 1. Why is carbon capture insufficient to compensate for global emissions? Choose the false answer.**
 - a. Practical applications have capture rates below what we would desire
 - b. There isn't enough space underground to store all the carbon dioxide we capture
 - c. It would take up a huge amount of materials to capture and transport all emissions
 - d. It would be more efficient to use the energy to directly decarbonize
- 2. Why are critics questioning the possibility of GDP-emissions decoupling?**
 - a. It is impossible to fully eliminate the use of fossil fuels
 - b. It is impossible to support human well-being without economic growth
 - c. No sustained absolute decoupling has been observed anywhere in the world
 - d. It is impossible to convince people to stop consuming carbon-intensive products

Feedback

- This is the first edition of the course
- We really appreciate your feedback!
- **HOW will we ask for feedback?!**

Assignment

- **ADD ASSIGNMENT DESCRIPTION**
- Course team explains proposed group assignments
- Students make groups of 2/3
- Diversity of perspective preferred (don't just pick your friends!)

Thank you for your attention!

Next lecture: Defining Sustainability

Thursday, 11 September, 15:45-17:30, EEMCS Hall F

- Conceptualizing sustainability
- Defining sustainable ICT systems
- Frameworks for sustainability: planetary boundaries, circular economy, digital sufficiency
- Sustainability indicators: global warming potential, emissions reporting, carbon/energy/material/water intensity

Questions?