Coupling of energy system models with LCA data: approach, challenges and first results

Method and case study on the German energy system

Workshop on InNOSys: Integrated sustainability assessment and optimization of energy systems

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Motivation

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General challenges

Future energy systems require to consider:

- Access to energy
- Security of supply
- Affordability
- Influence on job allocation
- Acceptance
- Environmental burden shifting

⟹ Existing studies focus on costs + directly emitted CO_2

⟹ There is a need to combine multi-dimensional indicators and energy system models

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} **Life Cycle Assessment (LCA)**

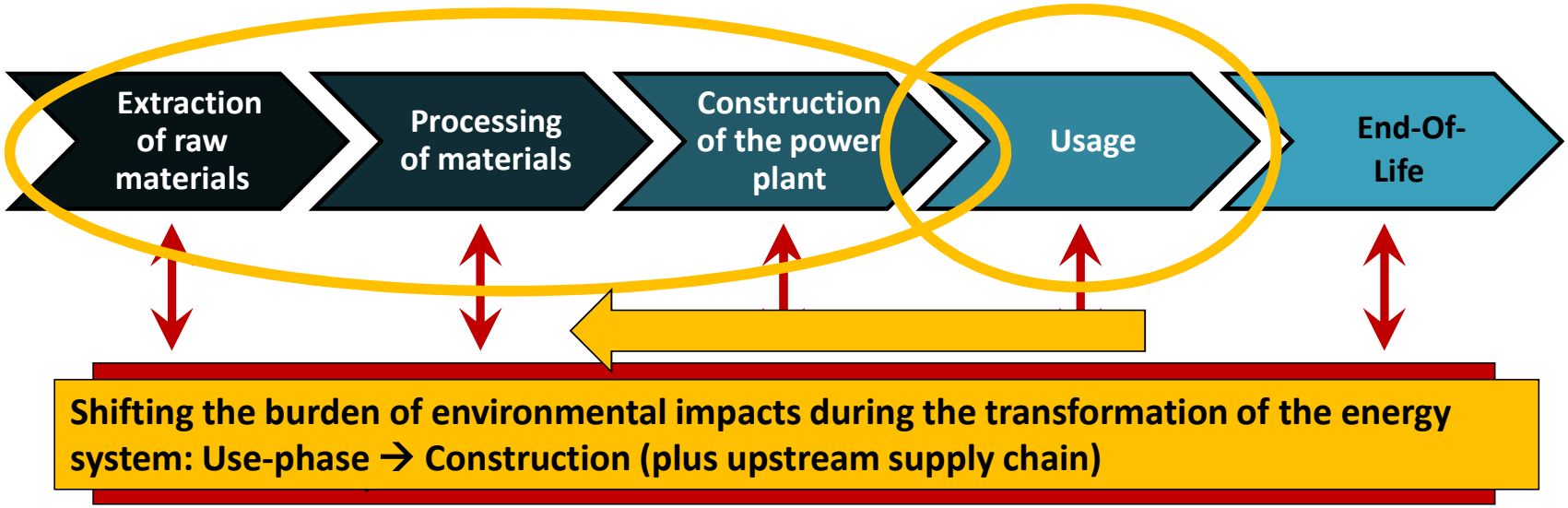
⇨ Existing studies focus on costs + directly emitted CO_2

⇨ There is a need to combine multi-dimensional indicators and energy system models

Motivation

Assessment of environmental burden shifting

Consideration of environmental impacts from *all* phases of a product's life cycle including upstream and downstream processes

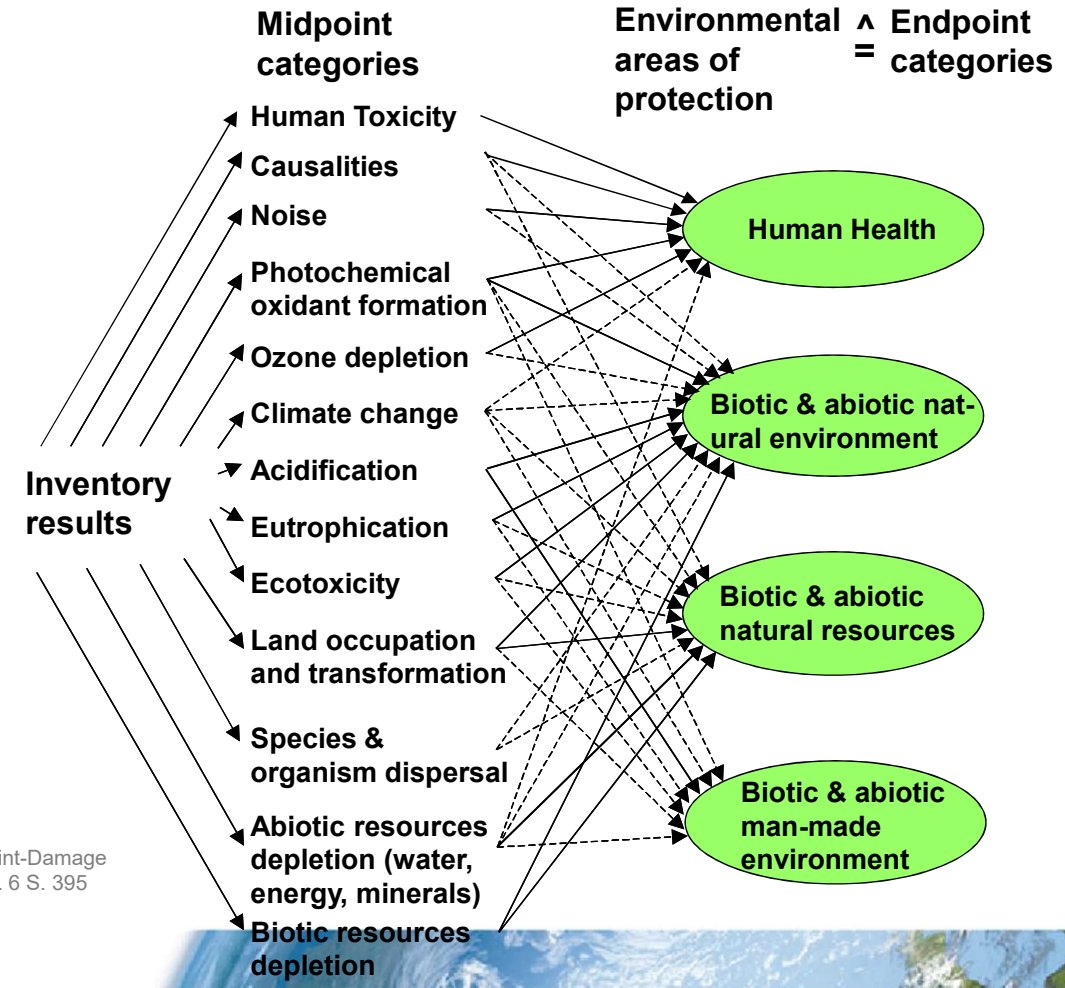


Methods

Methods

Introduction in life cycle assessment (LCA) - Life cycle impact assessment (LCIA)

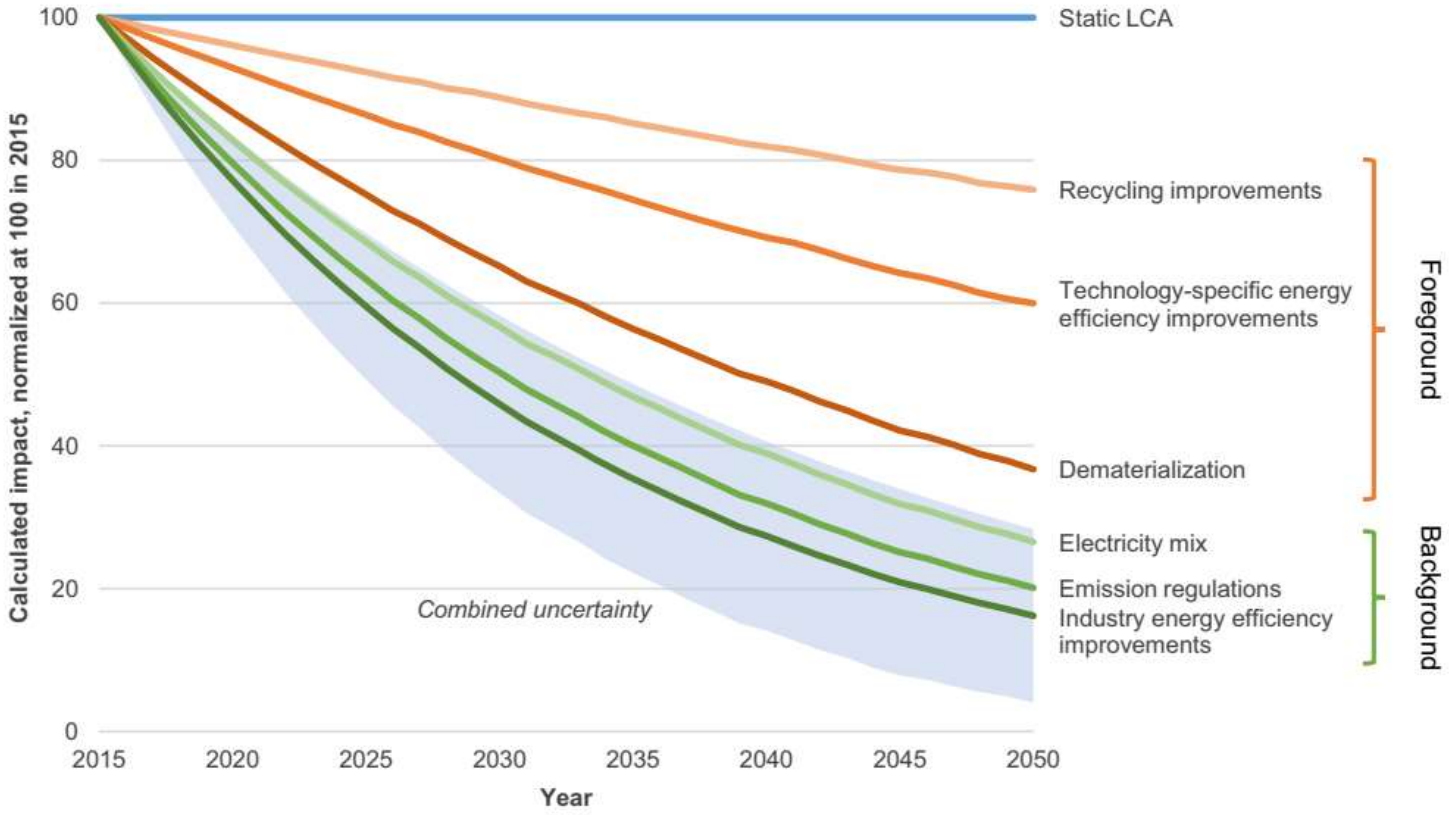
Different impact pathways from Midpoint to Endpoint



Adapted from Jolliet et al.: The LCIA Midpoint-Damage Framework .... Int. Journal of LCA 2004, Nr. 6 S. 395

Methods

Need for prospective indicators



L. Vandepaer and T. Gibon, “The integration of energy scenarios into LCA: LCM2017 Conference Workshop, Luxembourg, September 5, 2017,” The International Journal of Life Cycle Assessment, vol. 23, no. 4, pp. 970–977, 2018.

Methods

Global energy scenario (foreground):
- Electricity and heat generation
- Newly installed capacities and decommissioning (electricity, heat)
- Vehicle fleet development + fuel consumption
- Technical parameters of technologies

LCI data (adapted) Energy technologies
For foreground scenario (construction, operation)

Life Cycle Impact Assessment (LCIA)
Environmental impacts of energy technologies

Aggregation according to scenario

Environmental impacts of energy scenario

LCI data of today's energy technologies

LCI databases:
Ecoinvent, BioEnergieDat

LCI data from secondary literature
- Remodelling; background processes from Ecoinvent

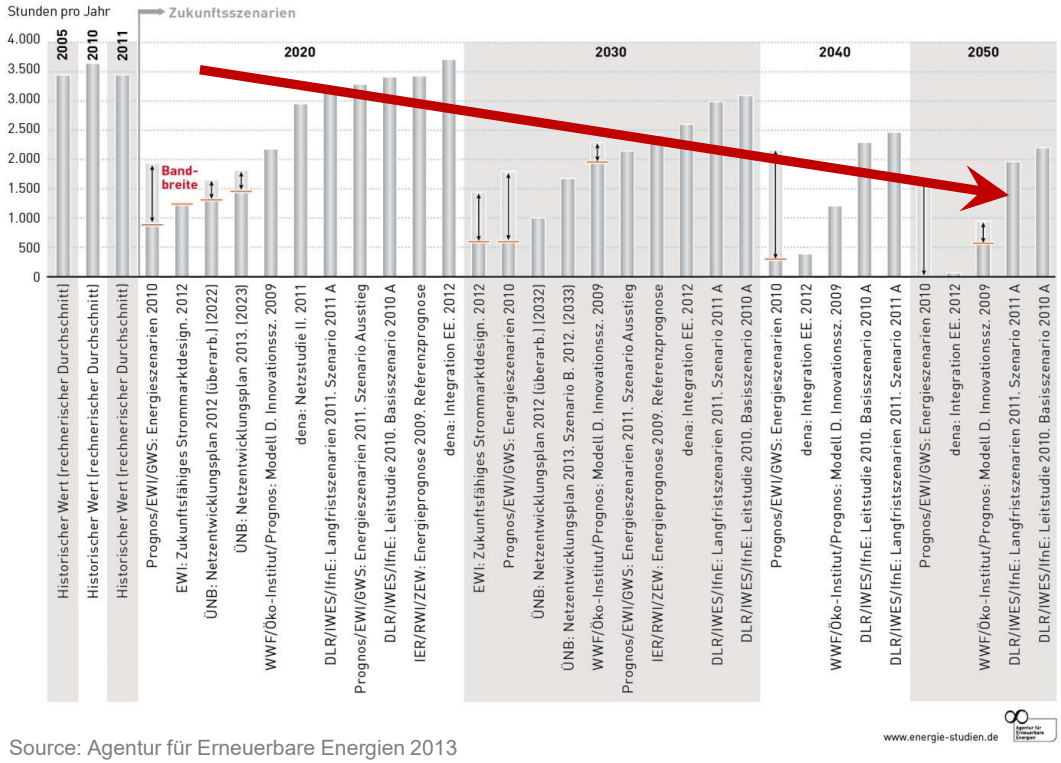
Adaptation/Dynamization of LCI data:
- Separation of construction and operation
- Modelling of fuel markets
- Full load hours and service life
- Efficiency, power to heat ratio, COP, for energy technologies
- Efficiency of relevant background processes (e.g. steel, copper and concrete production)
- Electricity mix upstream chain (from background scenario)

Global energy scenario (background):
Technology mix for power generation in 10 world regions 2015-2050 for individual support years

Methods

Dynamization of life cycle inventory

Development of average full load hours of gas-fired power plants



Source: Agentur für Erneuerbare Energien 2013

Reduction in capacity utilization:

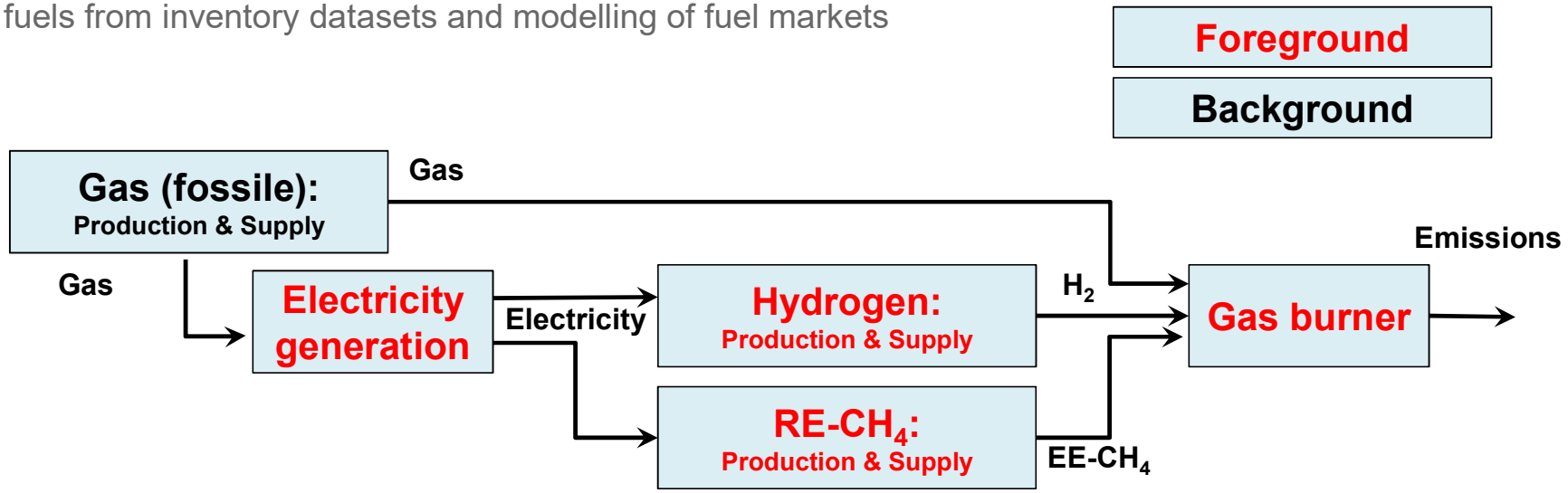
- Reduced environmental impact (EI) during operation
- Unchanged EI Construction & Deconstruction

⇨ **Separate EI in construction, operation and dismantling to adapt to capacity utilization according to the scenario!**

⇨ **Year-specific assignment of EI possible**

Methods

Excluding fuels from inventory datasets and modelling of fuel markets



In the event that energy sources are generated in the foreground system (electricity, district heating, synthetic gases and fuels):

- Separate the input of these energy sources from the (end-) consumption technologies
- Environmental impact separately determined using these energy sources in (end-) consumption technologies by modelling of markets in the LCI-databse

⇨ Adjustment of energy carrier mix to scenario assumptions possible

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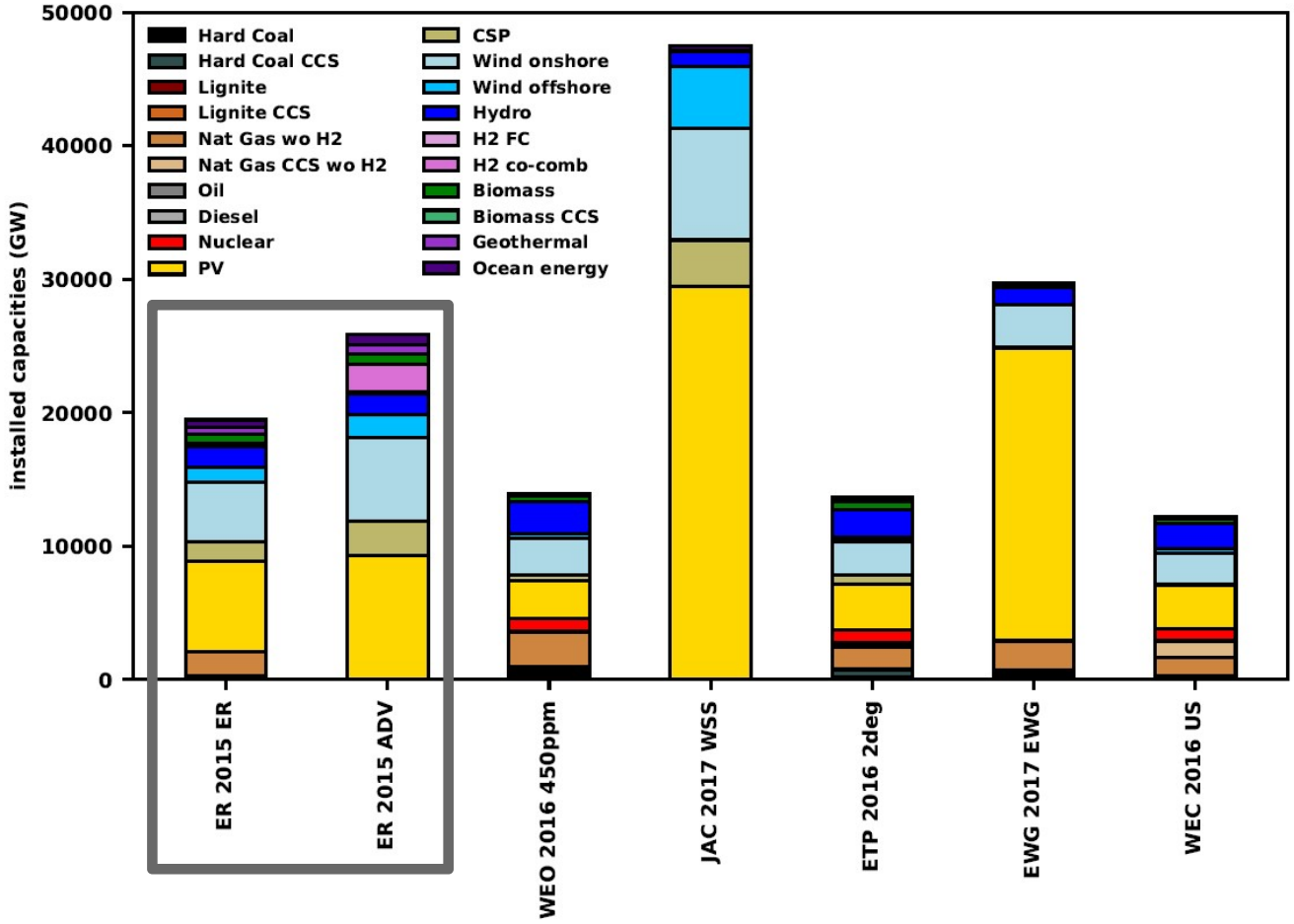
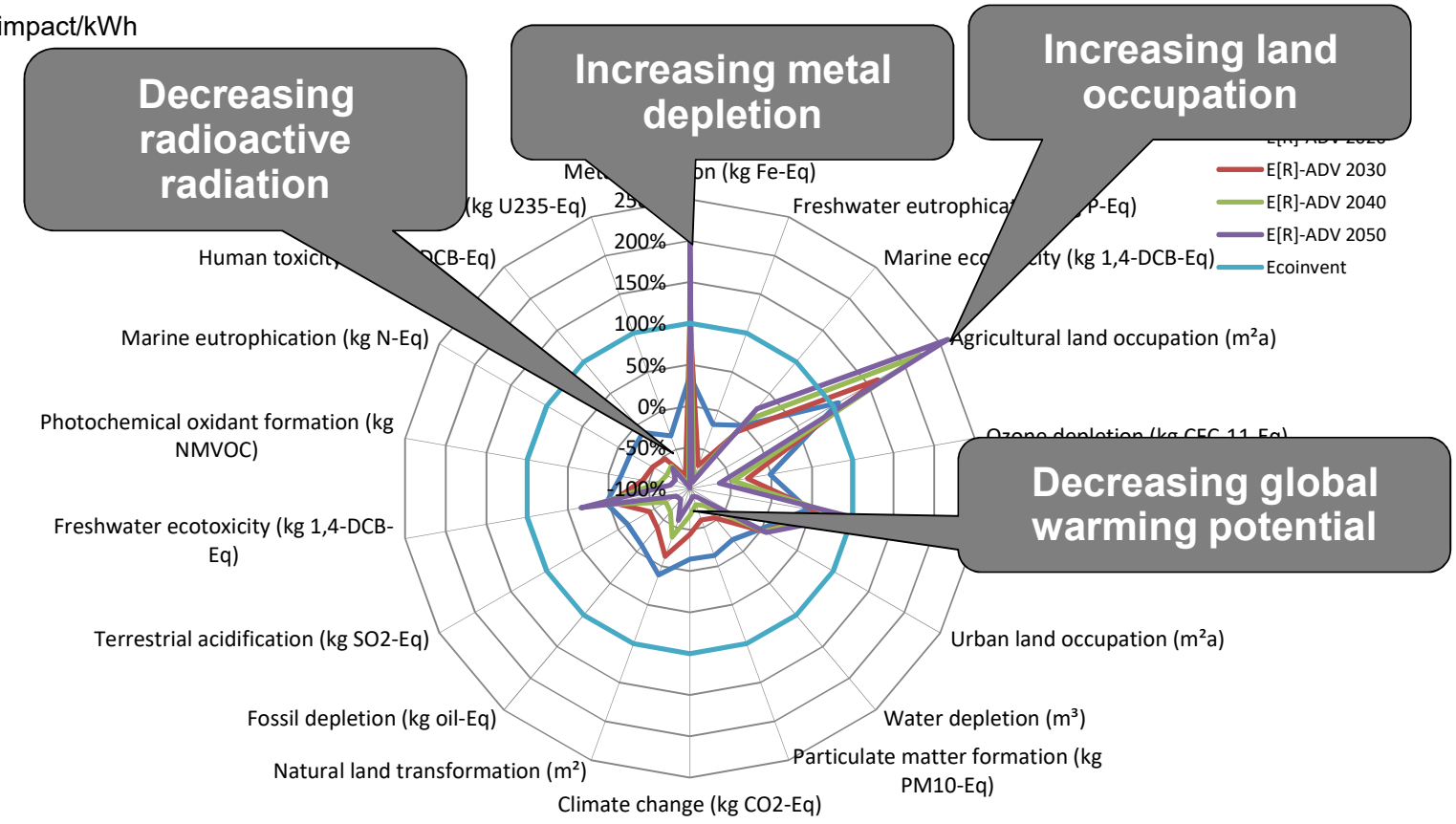
Adaption of background database - Energy [R]evolution scenarios



Background database

Effects of prospective electricity mix used as input to all processes in the LCI-database

Global electricity mix - impact/kWh



Challenges (I)

Database and methodology

Database and LCIs

- Old data and limited number of technologies (few storage technologies, wind turbines with PM), re-modelling required
- Low geographical resolution in ecoinvent (e.g. only global production of power plants)
- It is not always possible to fully match the technologies of the energy system model and the LCI database
- Some emissions from conversion processes are missing in the LCI database (e.g. burning of biodiesel in motor vehicles)

Methodology

- No adjustment of transport and heat supply to specific (scenario) regions possible due to the structure of the database
- Double counting of emissions

Challenges (II)

Need for flexible, customized software

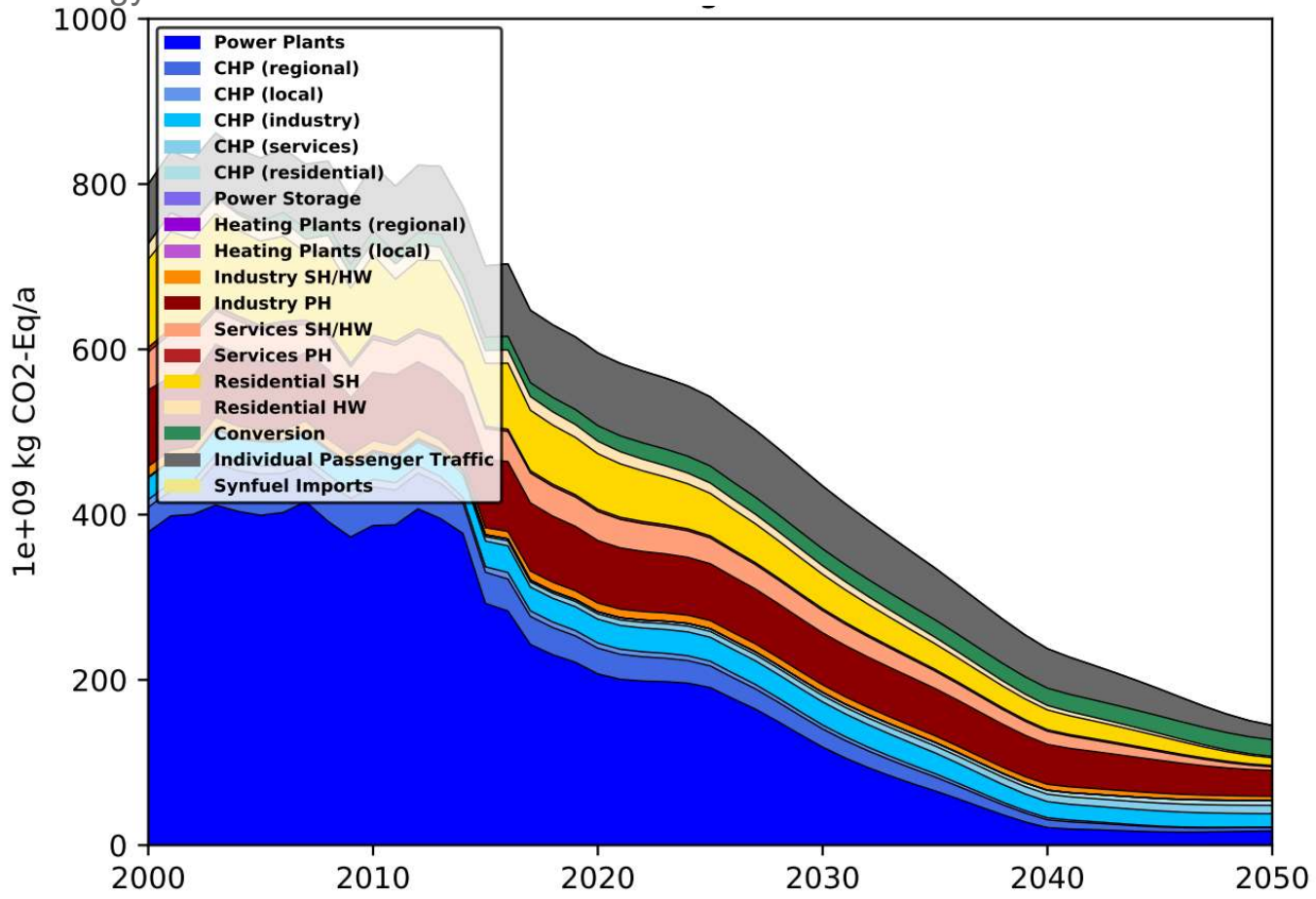
Software

- Computing speed and flexibility
- Automated Python interface with openLCA for parameterization and calculation of technologies (thereby relying on GreenDelta)

Results

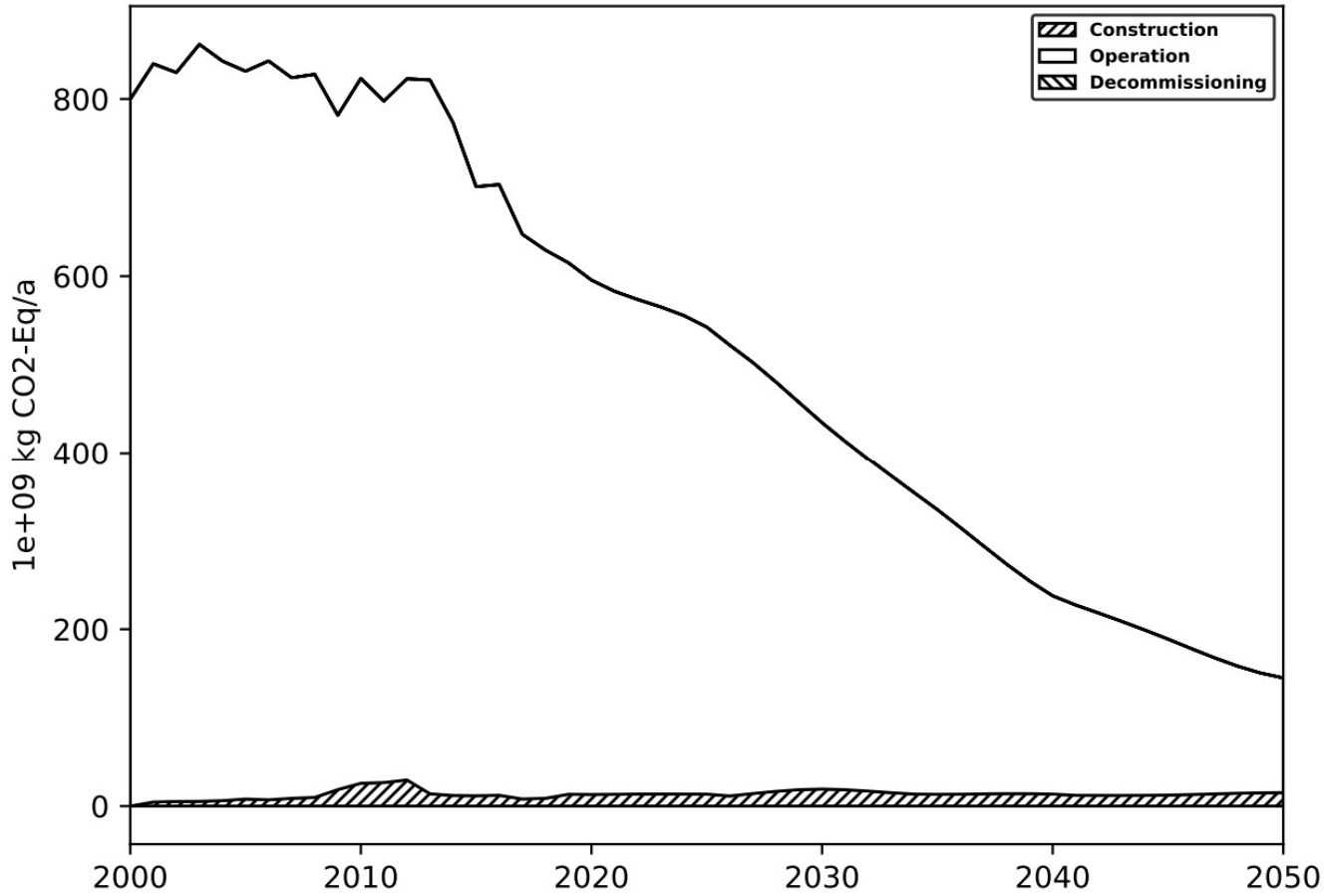
Results

Development of energy-related GHG emissions



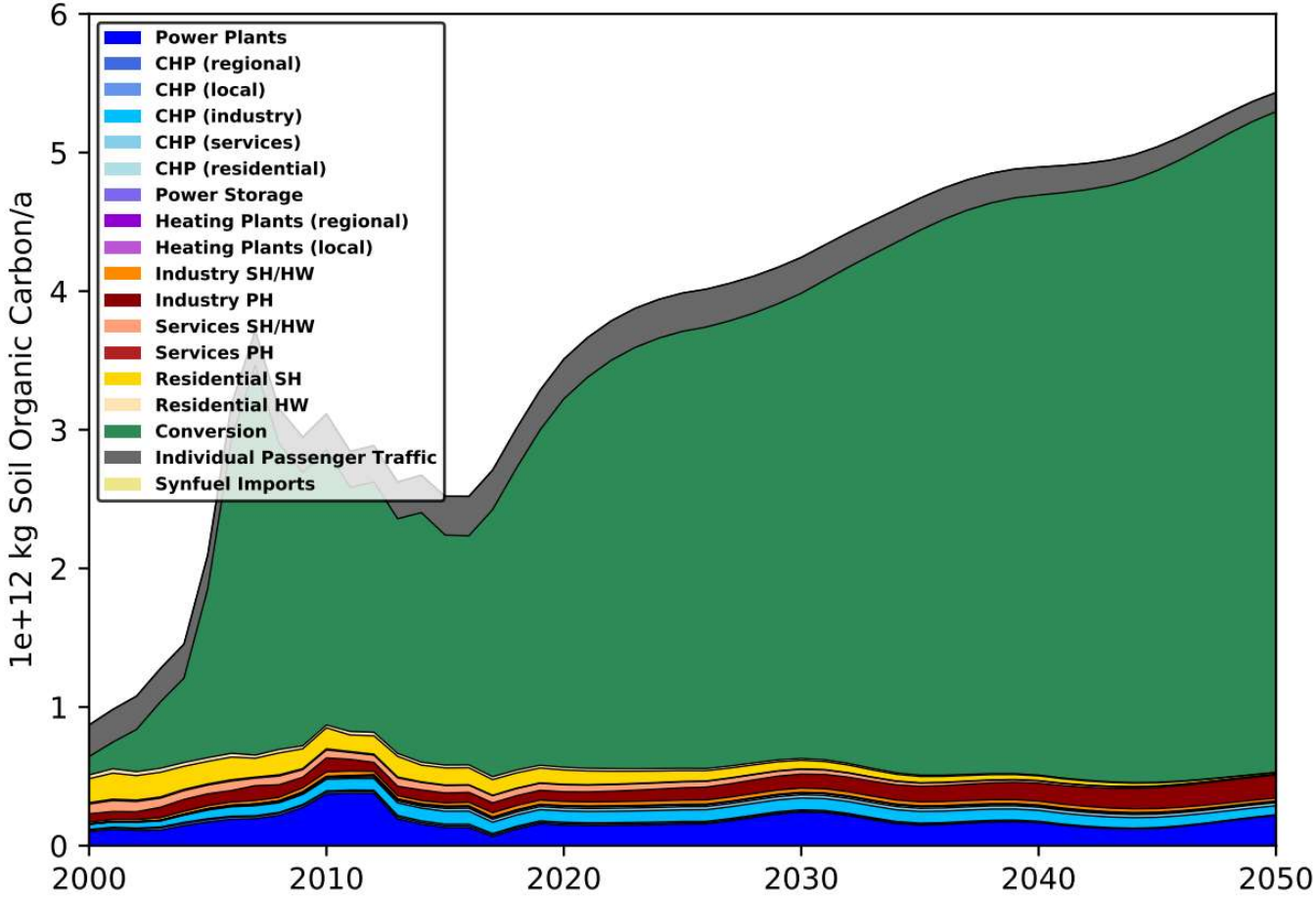
Results

Environmental impacts in the upstream supply chains become more relevant with increasing (direct) GHG reductions



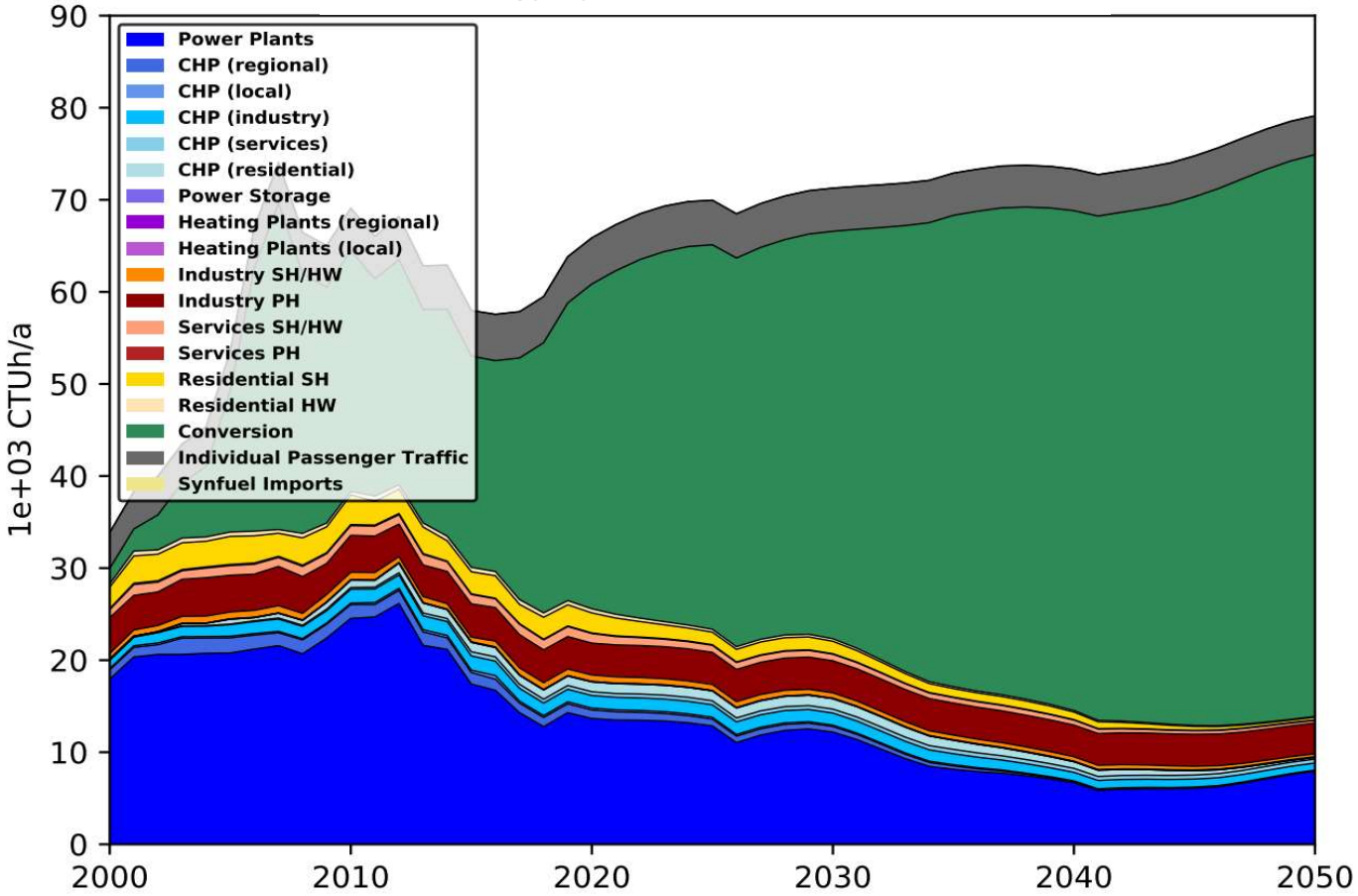
Results

Increased resource requirements due to the energy system transformation process



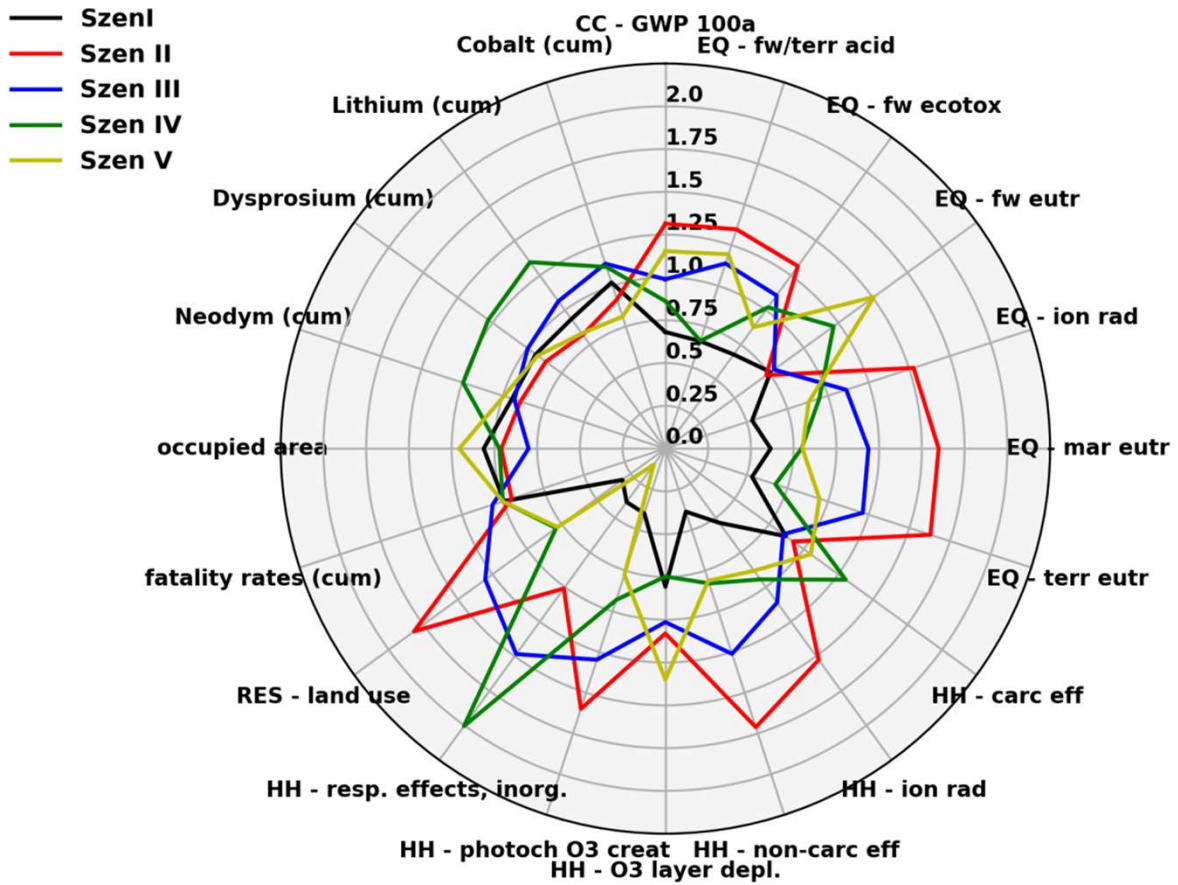
Results

Increased impacts on human health due to the energy system transformation process



Results

Systematic comparison of different transformation strategies



Take away

- **There are still many challenges in assessing transformation paths of the energy system with LCA-based indicators**

... Nevertheless, such an assessment metric is indispensable in future studies

We can quantitatively show that

- **Defossilisation strategies**

  ... do not automatically solve all environmental issues.

  They have low **GWP100 (CO_2eq.)**, but rely on severe **land-use** and **resource depletion**
- **Most environmental friendly solutions**

  … have a **low** share of PV in power generation and low shares of Li-Ion storages, but **high** shares of wind generation and grid expansion

  … also consider **hydrogen mobility** (next to BEVs) for the defossilisation of the transport sector

Questions to the audience

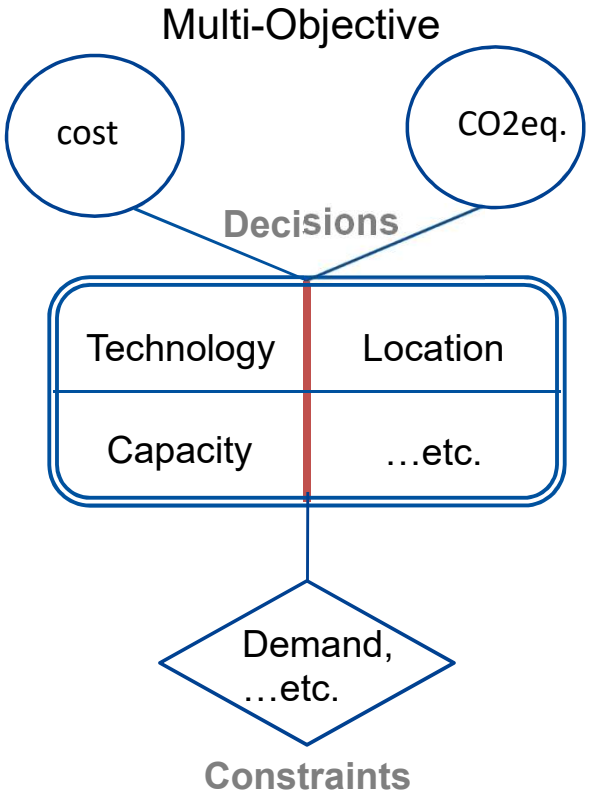
- Is the method of process based LCA suitable to assess the environmental burdens of large scale system transformations?
  - What kind of models have to be added (e.g. to capture economic impacts of the system transformation)
  - What kind of databases have to be added (such as IO tables)?

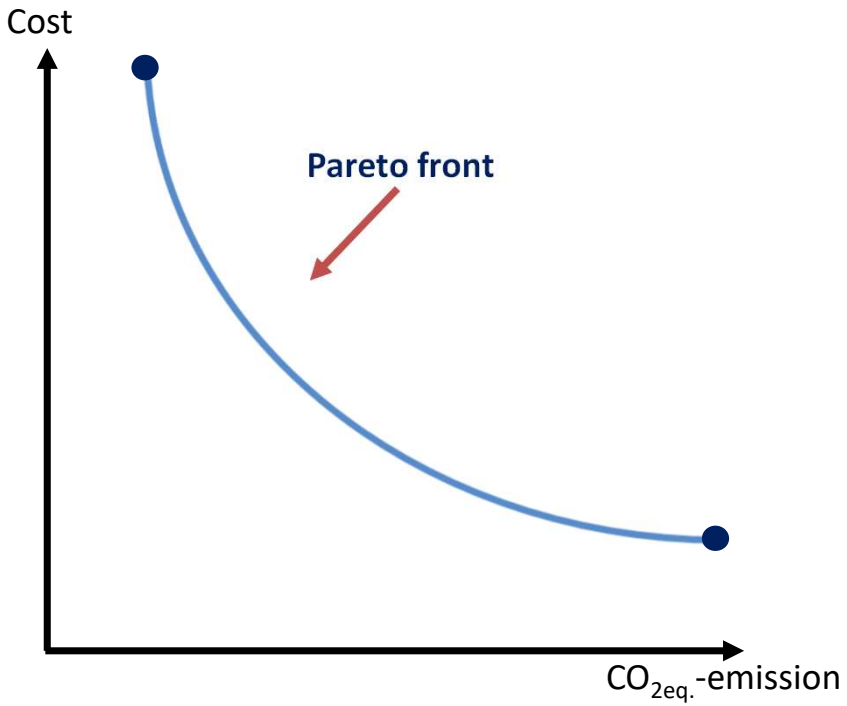
- How can we quantitatively assess co-benefits and adverse side effects between indicators?
  - Bivariate statistical regression analysis or multivariate approaches?

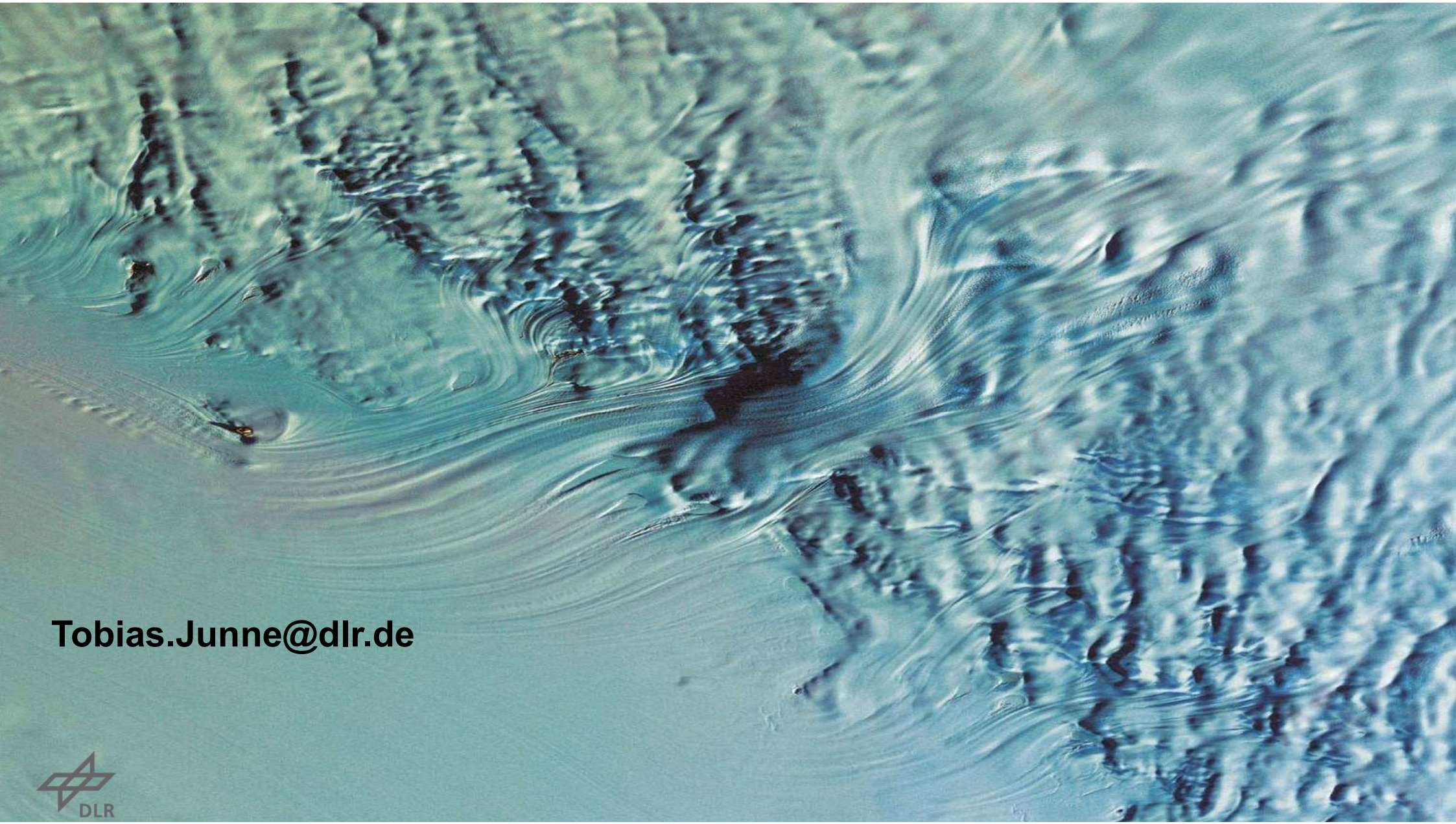
- How can we get more inventory results, will there be open data platforms?

Outlook

Assessment of trade-offs between system costs and LCA-based environmental impacts







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