Life cycle-based environmental impacts of energy system transformation strategies for Germany: Are climate and environmental protection conflicting goals?

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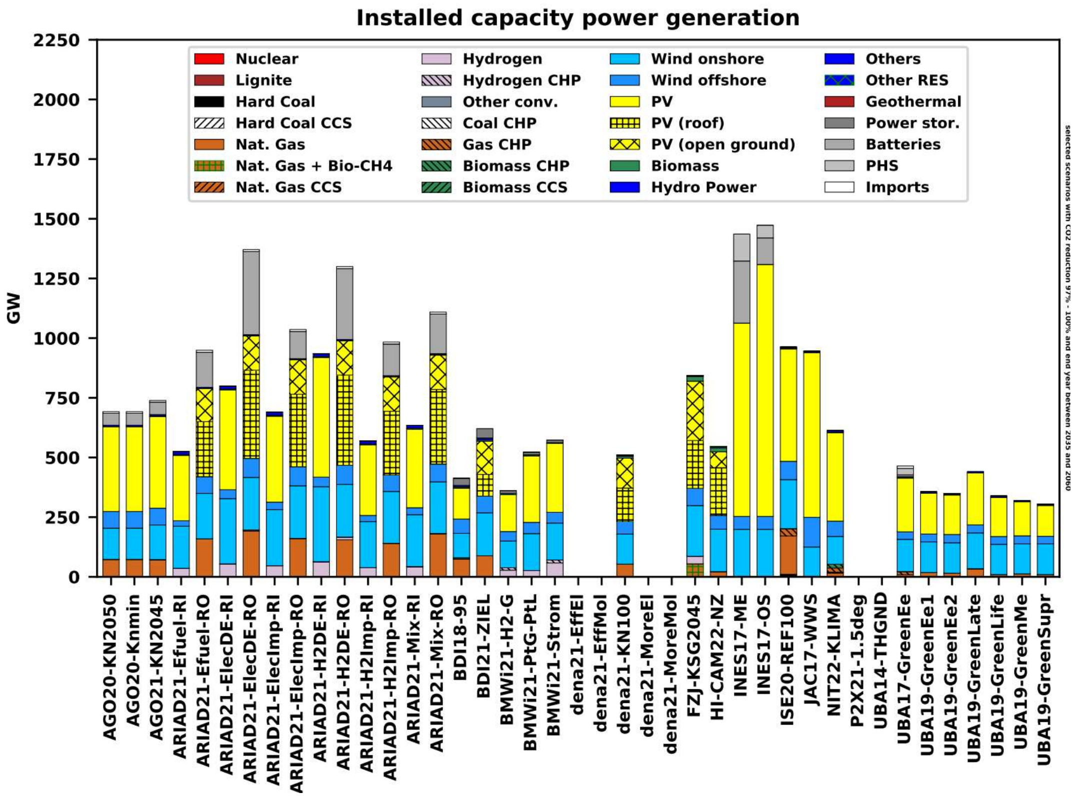
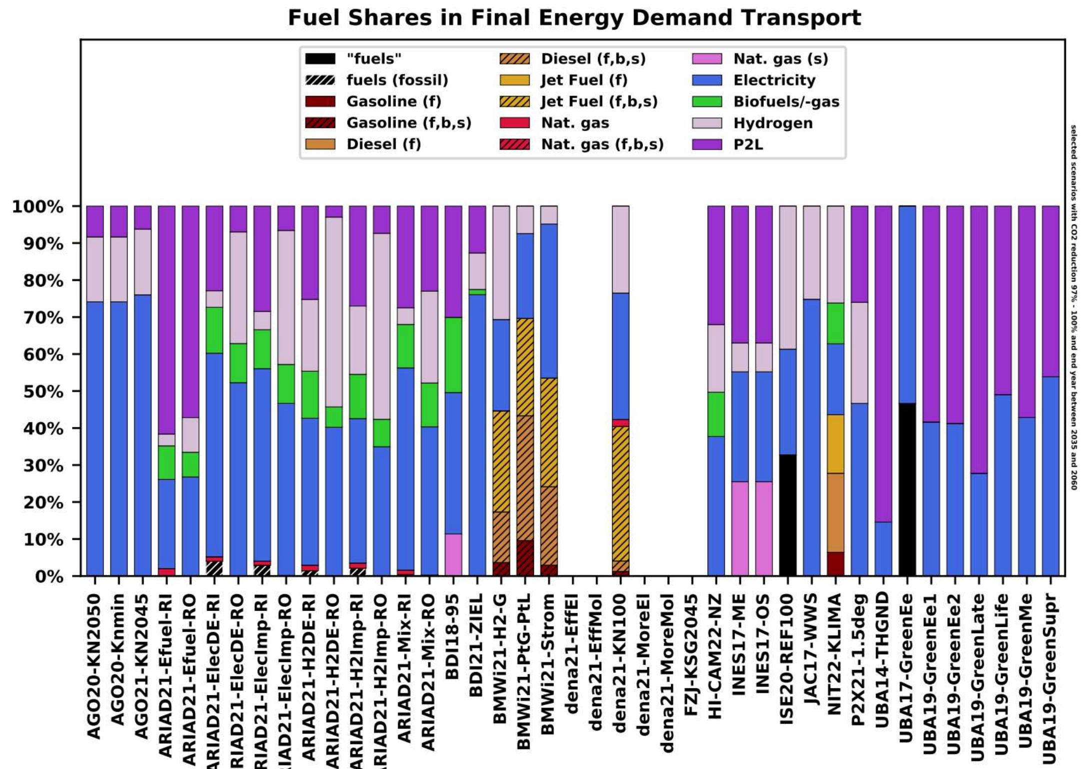
Motivation





Many studies describe technically and economically feasible strategies for a climate-friendly energy system, but they propose structurally quite different transformation concepts.

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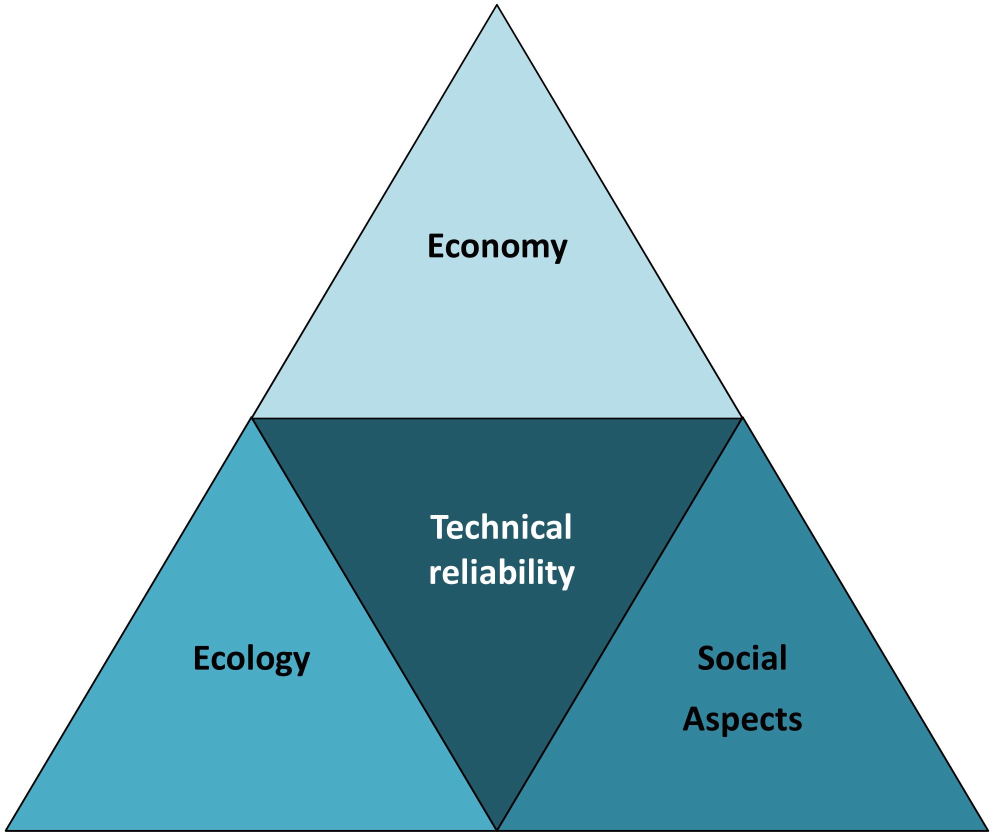
Motivation

Climate protection only one sustainability goal among many others. A transformation strategy of the energy system that considers only climate neutrality and low costs falls short!

Motivation: *Sustainable* Transformation Strategies for Energy Systems

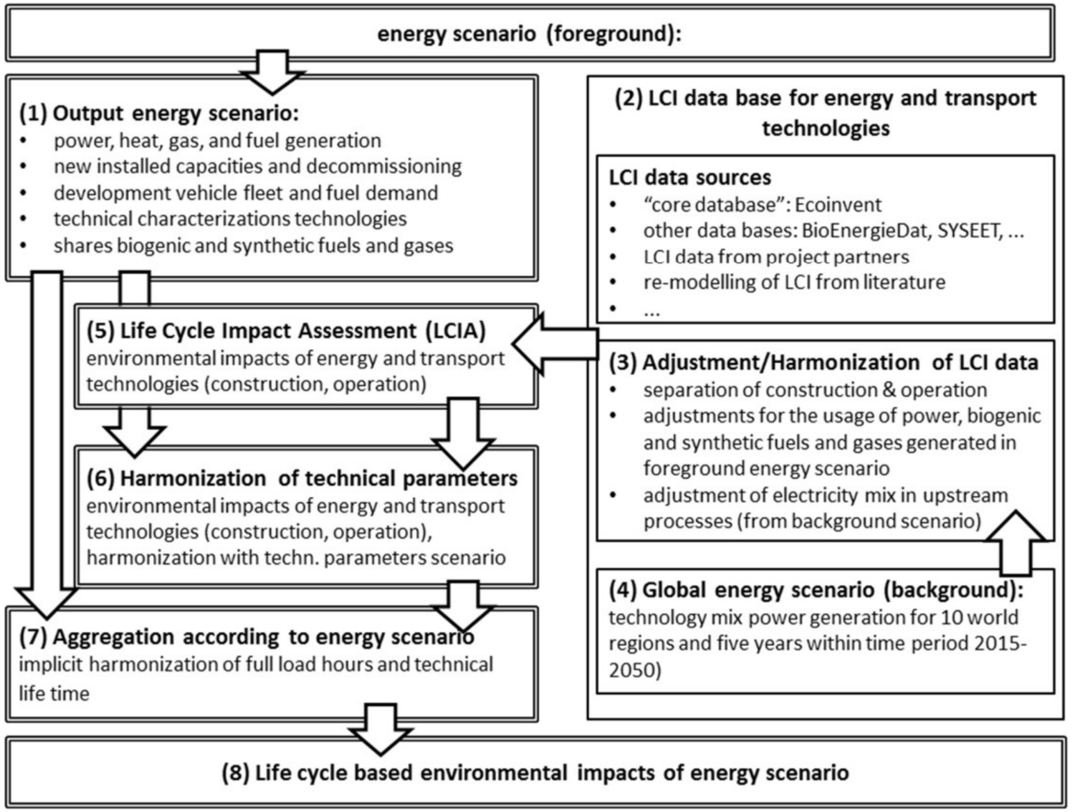
- Long-term goals:
  - Multidimensional impact assessment for transformation strategies of the entire energy system as
    - Decision aid to identify pros and cons of different transformation strategies
    - Early warning system to avoid undesired side effects of the transformation
  - Development of transformation strategies which are sustainable in a broader sense
- Approach for ecologic impacts: Coupling of energy system modelling with Life Cycle Assessment (LCA) data for energy and transport technologies

→ Estimation environmental impacts of transformation strategies for all life cycle phases including impacts from upstream processes



FRITS: Framework for the Assessment of Environmental Impacts of Transformation Scenarios

- Coupling of energy system models with LCI database for energy and transport technologies
- Separation of construction & operation
- Prospective adjustment of LCI data (power mix)
- Comprehensive harmonization of data in ESM and LCI database (efficiency, double counting)
- Methodological challenges:
  - Availability, representativeness, up-to-dateness and quality of LCI data
  - Consistent prospective adjustments of background system in LCI database
  - Avoidance of double counting
  - …



Junne et al.: Environmental sustainability assessment of multi-sectoral energy transformation pathways: Methodological approach and case study for Germany, Sustainability 12 (2020), https://www.mdpi.com/2071-1050/12/19/8225

Ecologic indicators used here

Category		Indicator	Unit
Midpoint indicators	Climate Change	Climate change	kg CO_2 eq
	Ecosystem quality	Freshwater and terrestrial acidification	mol H^+ eq
		Freshwater ecotoxicity	CTUe
		Freshwater eutrophication	kg P eq
		Marine eutrophication	kg N eq
		Terrestrial eutrophication	mol N eq
	Human health	Carcinogenic effects	CTUh
		Non-carcinogenic effects	CTUh
		Ionizing radiation	kg U^{235} eq
		Ozone layer depletion	kg CFC-11 eq
		Photochemical ozone creation	kg NMVOC eq
		Respiratory effects, inorganics	disease incidence
	Resources	Fossils	MJ
		Minerals and metals	kg Sb eq
		Land use	points
		Dissipated water	m^3 water eq
Aggregated indicator		Environmental Footprint 2.0	dimensionless

References: Fazio et al. 2018, Supporting information to the characterization factors of the recommended EF Life Cycle Impact Assessment Method – new models and differences with ILCD, European Commission 2018, European Platform on Life Cycle Assessment. Developer Environmental Footprint (EF): EF reference package 2.0 (pilot phase)

Scenarios selected as "inspiration"

No.	Funding Agency, title and year of original study	Scenario Variant	Research Institutions
I	BMWi: Gesamtwirtschaftliche Effekte der Energiewende (2018)	EWS	GWS, Prognos, DIW, FhG ISI, DLR
II	BMWi: Langfristszenarien für die Transformation des Energiesystems in Deutschland (2017)	Basis	FhG ISI, ifeu, Consentec
III	BMU: Langfristszenarien und Strategien für [illegible] (2012)	[illegible]	DLR
IV	BMU: Klimaschutzszenario 2050 (2015)	KSSz80	Öko-Institut, FhG ISI, Ziesing
V	FhG ISE: Was kostet die Energiewende? Wege zur Transformation des deutschen Energiesystems (2015)	80-g-H2-nb	FhG ISE
VI	BMU: Klimaschutzszenario 2050 (2015)	KSz95	Öko-Institut, FhG ISI, Ziesing
VII	BEE: GROKO II – Szenarien der deutschen Energie-versorgung auf Basis des EEG-Gesetzentwurfs (2014)	100	J. Nitsch
VIII	UBA: Den Weg zu einem treibhausgasneutralen Deutschland ressourcenschonend gestalten (2017)	GreenEE	ifeu, FhG IWES, CONSIDEO, Dr. Schoer SSG
IX	INES: Erneuerbare Gase – ein Systemupdate der Energiewende (2017)	OptSys	enervis energy advisors GmbH
X	dena: Leitstudie integrierte Energiewende (2018)	TM95	ewi Energy Res. & Scen. gGmbH

„moderate" climate protection scenarios: reduction of direct CO_2 emissions ca. 80% (I–V)

„ambitious" climate protection scenarios: reduction of direct CO_2 emissions ca. 95% (VI–X)

Harmonised re-modelling of scenarios necessary

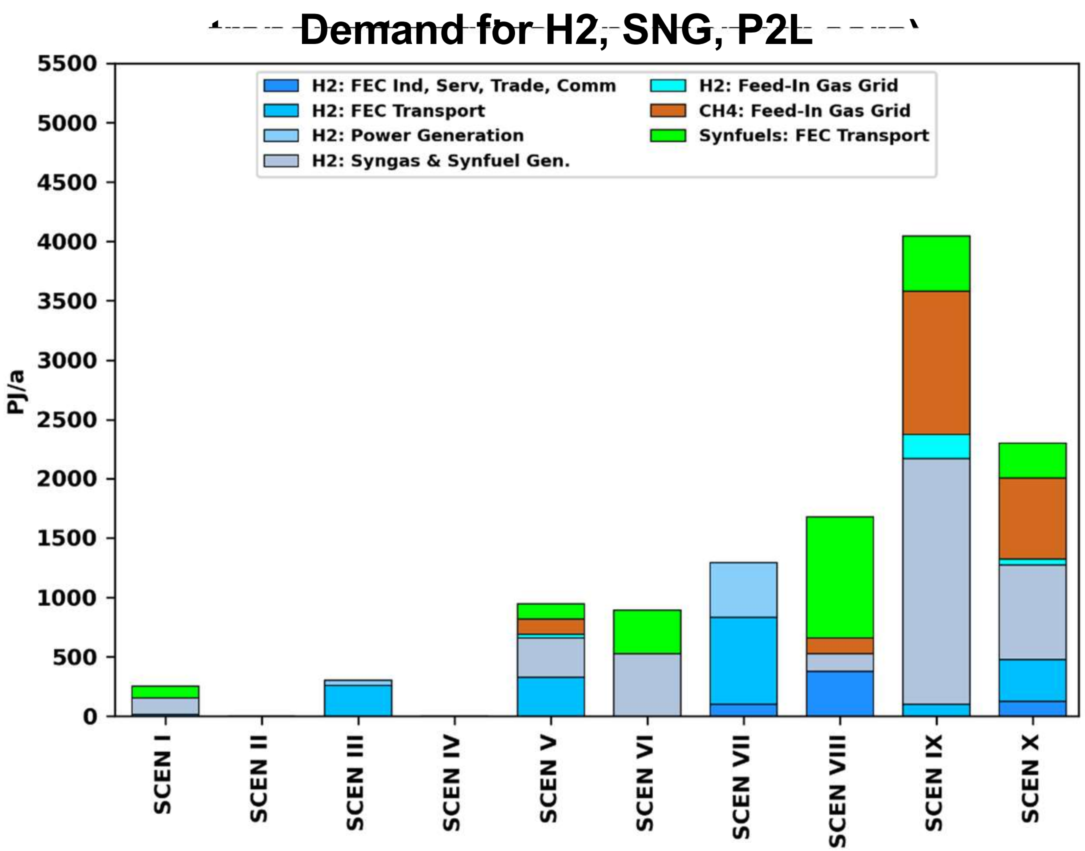
Challenges:

- **Reported quantities not sufficient** to perform analysis with FRITS
- **Different boundary conditions:**
  - GDP, population, efficiency, modal split, …
    → transport services, useful energy demand, …
  - Techno-economic performance of technologies

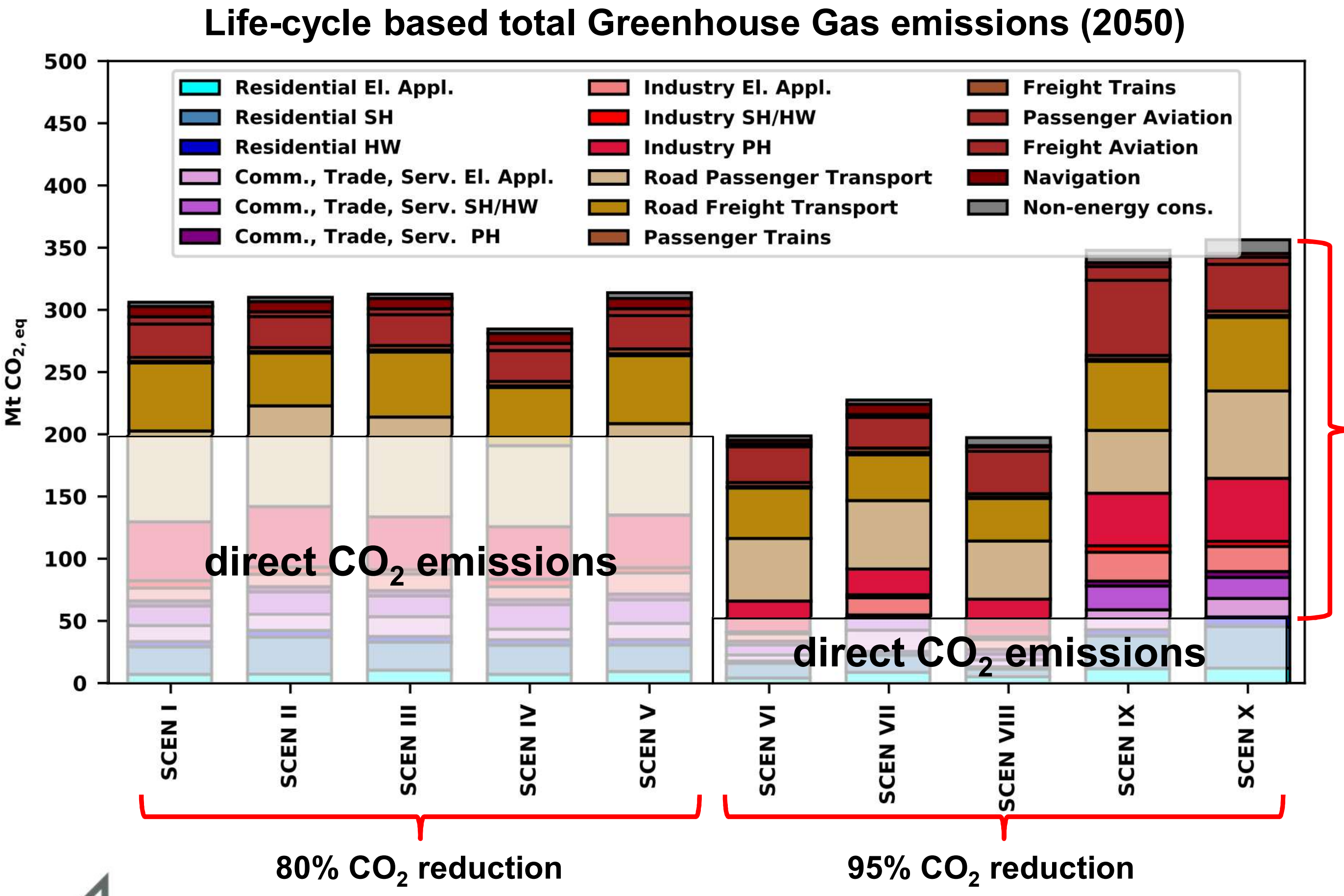
→ potential **bias in impact assessment, solution:**

Consistent, harmonised re-modelling of scenarios

- **Re-modelling** in a single model framework
- **Harmonisation of boundary conditions**
- Use „**technical storyline“ from original studies**: Development of market shares of technologies and/or energy carriers within each sector taken



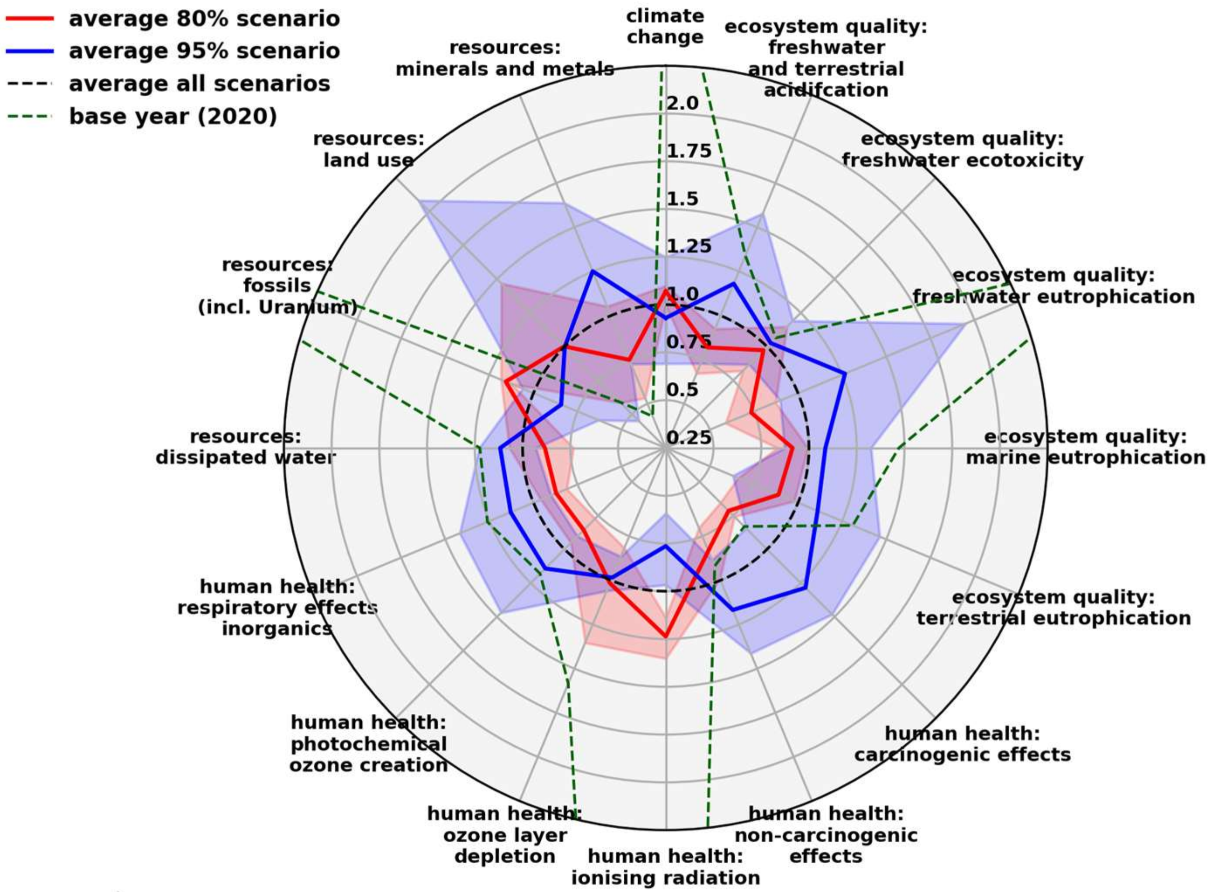
Life cycle perspective matters!



- Life-cycle perspective matters!
- GHG emissions from upstream processes might be higher than those of foreground system
- LC-based GHG emissions from 95% scenarios might be higher than those from 80% scenarios
- (Discrepancy between direct and LC emissions is expected to decrease with further prospective adjustments in background data base, .e.g. for industrial processes)

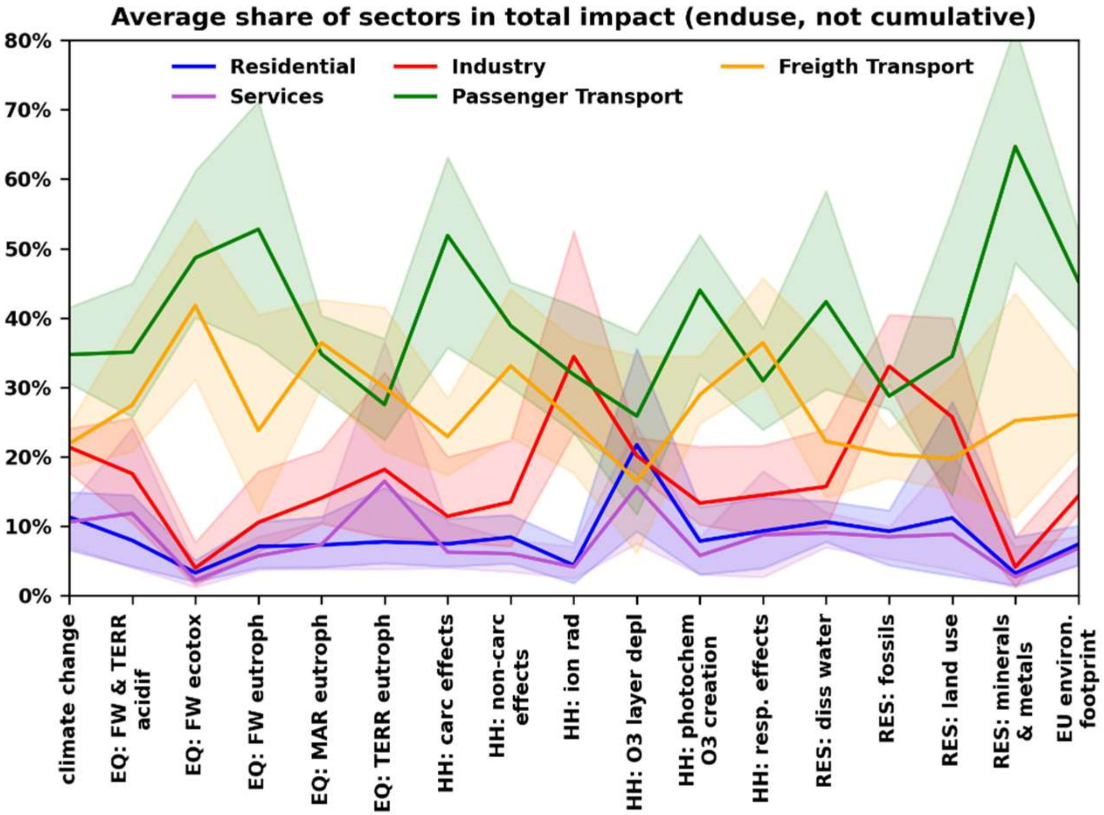
emissions from upstream processes (background system) and non-CO_2 emissions
→ Remain undetected if only direct emissions considered!

Life-cycle based environmental impacts of transformation strategies



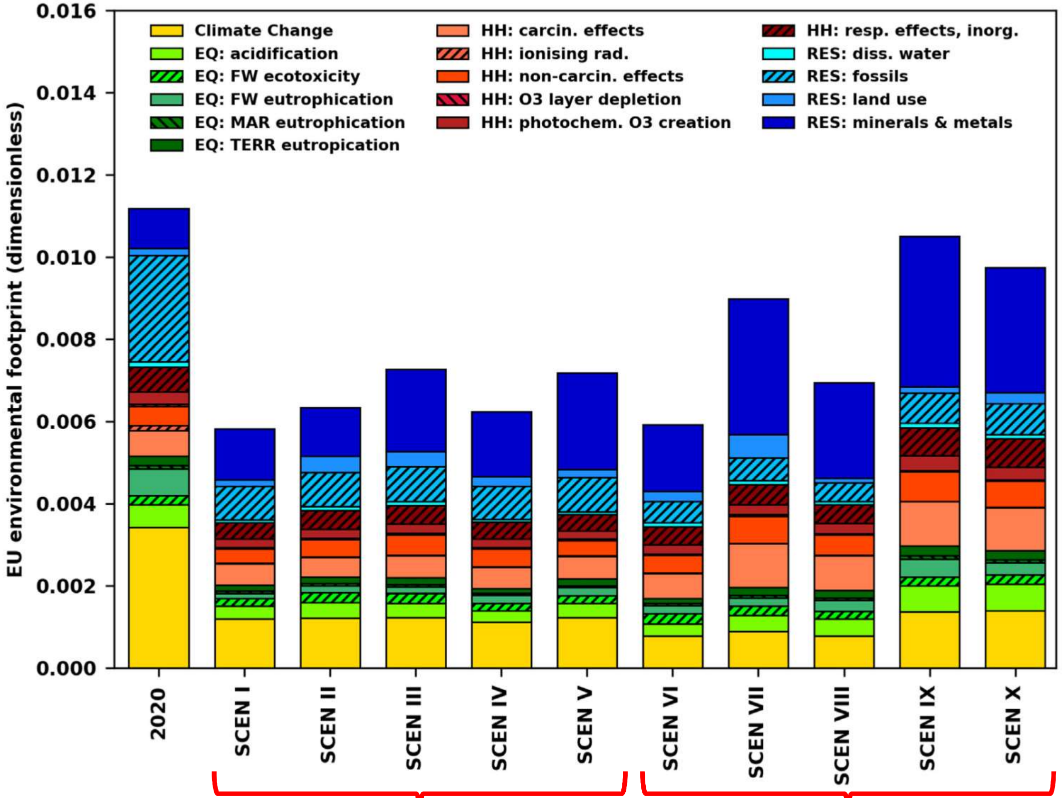
- Environmental impacts of the energy system decrease in most impact categories by 2050 compared to today.
- Exceptions: Mineral resources, land use, depending on scenario also certain aspects of human health and ecosystem quality
- More climate protection does not always mean lower other environmental impacts!
- Cause: Higher degree of direct and indirect electrification in ambitious scenarios requires
  - Higher impacts from electricity infrastructure (electricity generation and storage)
  - Higher impacts from new conversion technologies (P2X)
  - Higher impacts from vehicles with "new" drive concepts (BEVs, FCEVs, ...)

Life-cycle based environmental impacts of transformation strategies



- Environmental impacts from the transport sector dominate in most impact categories.
- Cause: high environmental impacts from the construction of BEVs & FCEVs as well as the provision of biofuels, if applicable.
- Impacts from vehicle operation comparatively low

Life-cycle based environmental impacts: EU Environmental Footprint (EF) as an aggregated indicator



„moderate" strategies (-80%) „ambitious" strategies (-95%)

- Aggregated environmental impacts decrease in all scenarios by 2050 compared with 2020
- Remaining (LC-based) GHG emissions and mineral consumption are main drivers of EF
- Large spread among „ambitious" strategies

Ambitious climate protection offers the chance of low environmental impacts, but also poses a risk of higher impacts if the wrong strategy is chosen!

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Summary and conclusion

- A climate-friendly transformation of the energy system generally leads to a reduction of other environmental impacts as well (with some exceptions).
- There is a *risk* for comparably high impacts if the wrong strategy is chosen – in particular in ambitious scenarios.
- Transport is responsible for a large share of impacts in most impact categories:
    - Construction of vehicles with „new“ drive trains
    - Construction of power plants for direct or indirect electrification of transport
    - Electrolyzers, methanation and biofuels
- Strategies for environmentally- *and* climate-friendly energy systems imply:
    - Reduced number and size of BEVs (in particular batteries in those vehicles)
    - Reduction of environmental impacts at construction stage (BEVs, FCEVs, …)
    - Electrification of heat and transport as moderate as possible: if possible direct electrification instead of indirect electrification via P2X; if possible use of environmental, geothermal or solarthermal heat.
    - Balanced power generation mix (no excessive PV installations)

Thank you very much for your attention!

Questions, comments, suggestions?

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Literature

- Junne et al.: Environmental sustainability assessment of multi-sectoral energy transformation pathways: Methodological approach and case study for Germany, Sustainability 12 (2020), https://www.mdpi.com/2071-1050/12/19/8225
- Naegler et al.: Life cycle-based environmental impacts of energy system transformation strategies for Germany: Are climate and environmental protection conflicting goals?, Energy Reports 8 (2022), https://doi.org/10.1016/j.egyr.2022.03.143
- Junne et al.: Considering life cycle greenhouse gas emissions in power system expansion planning for Europe and North Africa Using Multi-Objective Optimization; Energies 14 (2021), https://doi.org/10.3390/en14051301