Multi-objective optimization of power system expansion

Methodological approach and main findings

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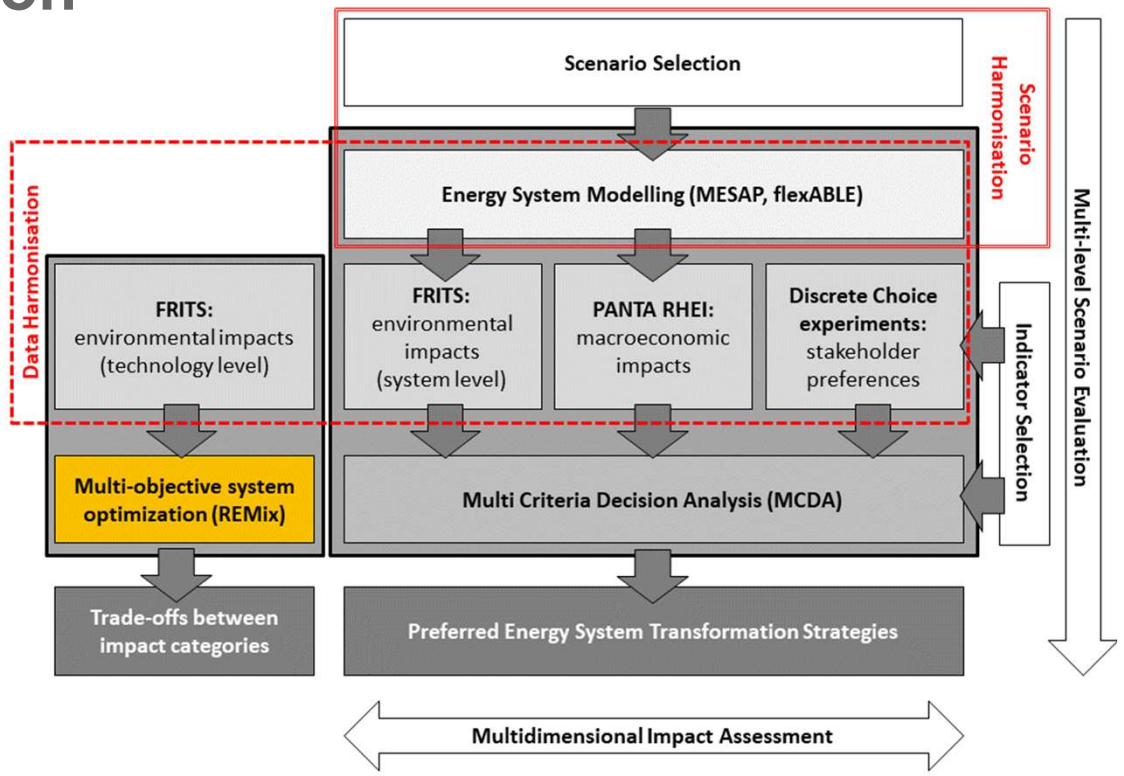


Motivation

Aim of the European Union:

Reduction of GHG

by 100% at best by 2050[1]

- **Installed capacity of RE and transmission rises**

Energy system optimization models (ESOMs) usually optimize on costs and only consider **direct CO_2 emissions constraints**

- Embedded emissions become more important!

Other **environmental impacts** are usually **not considered**

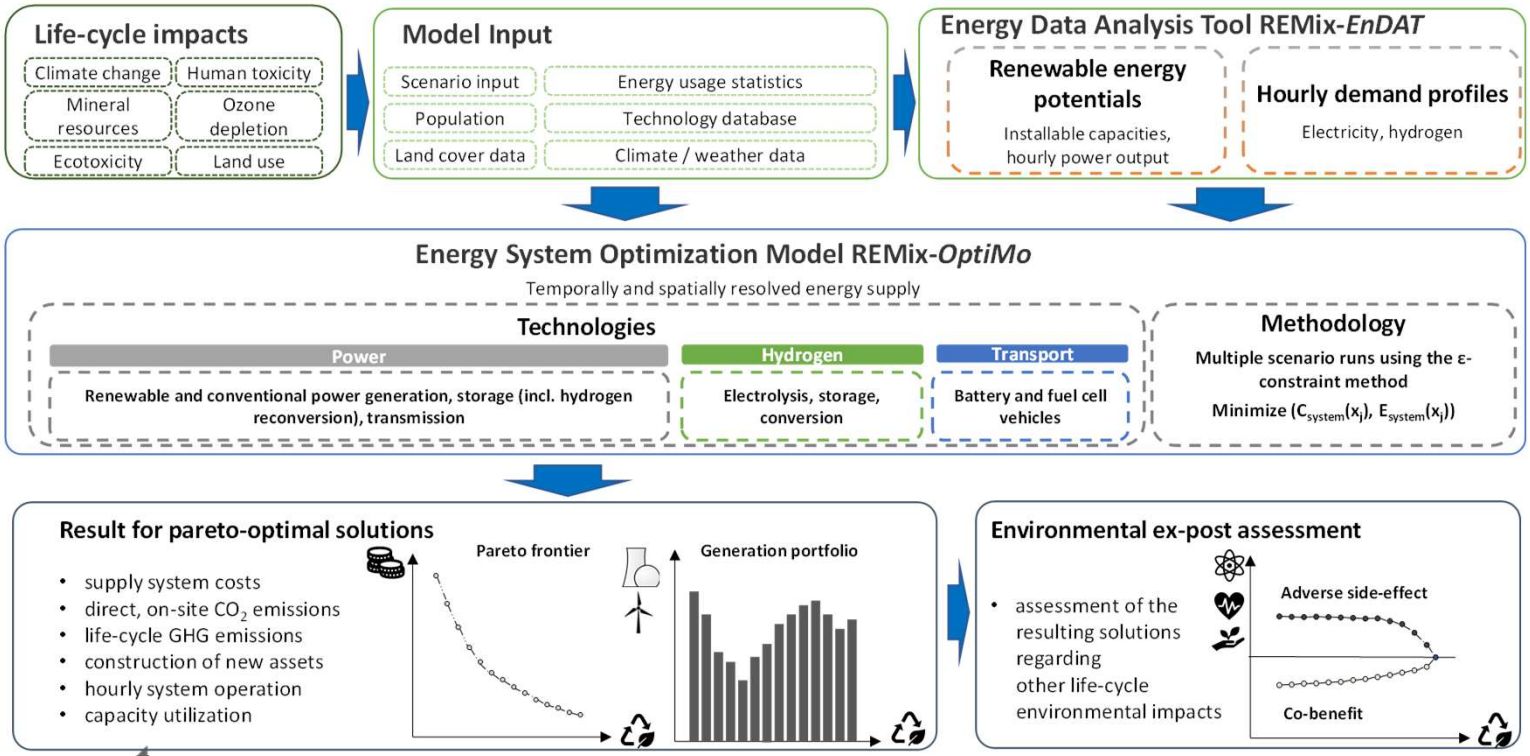
- Holisting **life cycle perspecive** needed!

LCA impacts should be co-optimized

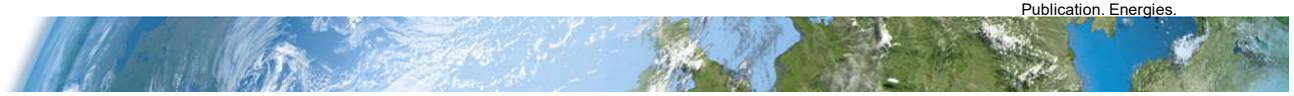
Integration of life cycle impacts into the optimization model REMix

[1]Source: European Commission (https://ec.europa.eu/clima/policies/eu-climate-action_en)

Modeling approach



Junne, T.; Cao, K.-K..; Miskiw, K.-K.; Hottenroth, H.; Naegler, T. Considering Life-Cycle Greenhouse Gas Emissions in Power Systems Expansion Planning for Europe and North Africa Using Multi-Objective Optimization. Accepted for Publication. Energies.



Modeling approach

Costs — „Main“ objective function

\+ Epsilon constraint method

LCA-based CO_2 eq — Constrained objective function

Calculation of the payoff table

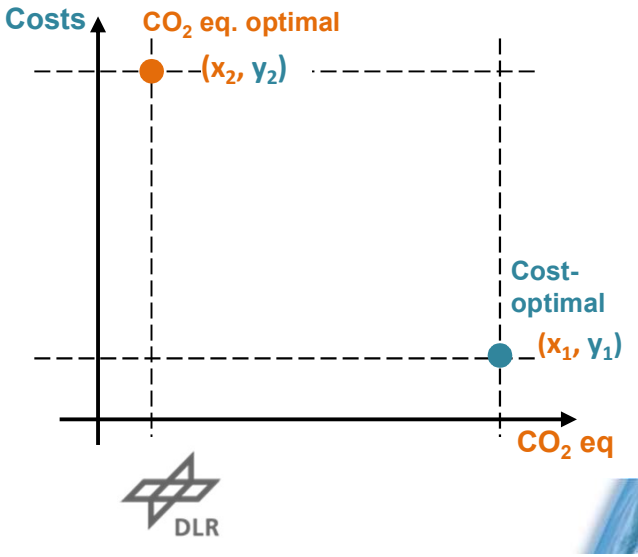
- Optimized twice, for each objective function once
- Defines solution area for solving

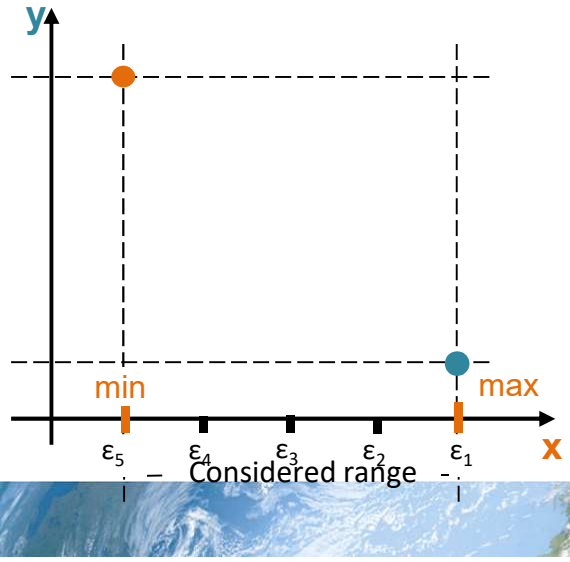
Defining the grid points

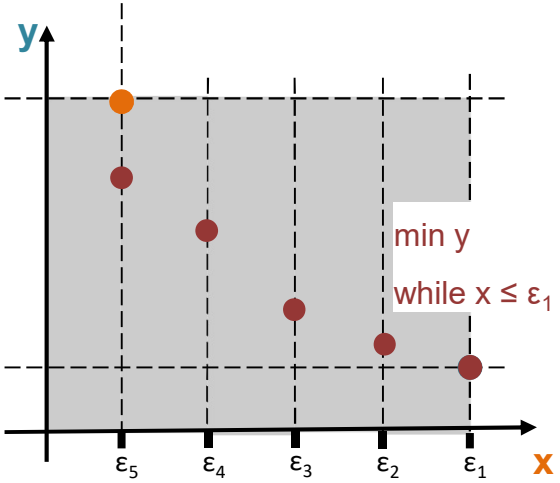
- Calculation based on best and worst value of the payoff table
- Divided by defined number of grid points g

Solutions for grid points

- Division in g sub problems
- Minimizing costs under the so called ε-constraint







Coverage of LCI data

Technology group	Technology in REMix	Corresponding LCI data
Electricity generation	PV open ground	Multi-Si panel Sinlge-Si panel
	PV rooftop	Multi-Si panel Sinlge-Si panel
	Concentrated solar power	Concentrated solar power plant (parabolic trough)
	Wind onshore	Wind onshore (geared)
	Wind offshore	Wind offshore (geared)
	Hydro reservoir	Hydro reservoir
	Hydro run-of-river	Hydro run-of-river
	Geothermal	Deep geothermal
	Nuclear power plant	Nuclear boiling water reactor
	Biopower	Wood-chip-biomass-fired plant (steam turbine)
	Lignite power plant	Lignite power plant
	Hard coal power plant	Hard coal power plant
	Open cycle gas turbine	Open cycle gas turbine
	Combined cycle gas turbine	Combined cycle gas turbine
Conversion	Electrolyzer	Alkaline water electrolysis (AEL)
Storage	Hydrogen storage (cavern)	Hydrogen storage in salt caverns
	Hydrogen storage (tank)	Carbon fiber hydrogen tank
	Vanadium redox-flow battery	Vanadium redox-flow battery
	Li-ion battery	Lithium-iron phosphate with lithium-titanate anode (LFP-LTO)
	SOFC fuel cell (hydrogen)	SOFC fuel cell
	Pumped hydro	Pumped hydro
Grid	HVDC line	HVDC overhead line for connections on land, sea cable for connections over water
	HVDC cable	HVDC land cable for connections on land, sea cable for connections over water

Assumption on sub-technology composition: 70% single-Si, 30% multi-Si[1]

Fixing the c-rate as disaggregation into converter and storage unit was not possible[2]

Subdivision into aerial lines and cables

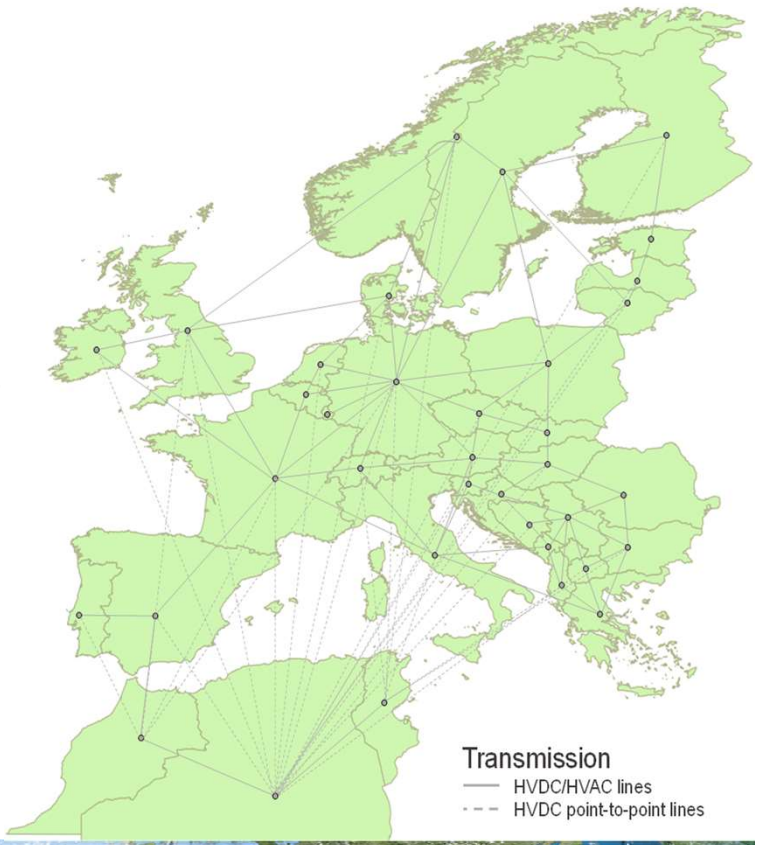
[1]Source: Photovoltaics Report Fraunhofer ISE. Available online: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

[2]For further details, see Junne, T.; Cao, K.-K.; Baumann, M.; Weil, M. Integration von Lebenszyklusdaten von Batterietechnologien in die Energiesystemmodellierung. In Proceedings of the 3. Jahrestreffen des Forschungsnetzwerks Energiesystemanalyse, Aachen, Deutschland, 23–24 May 2019

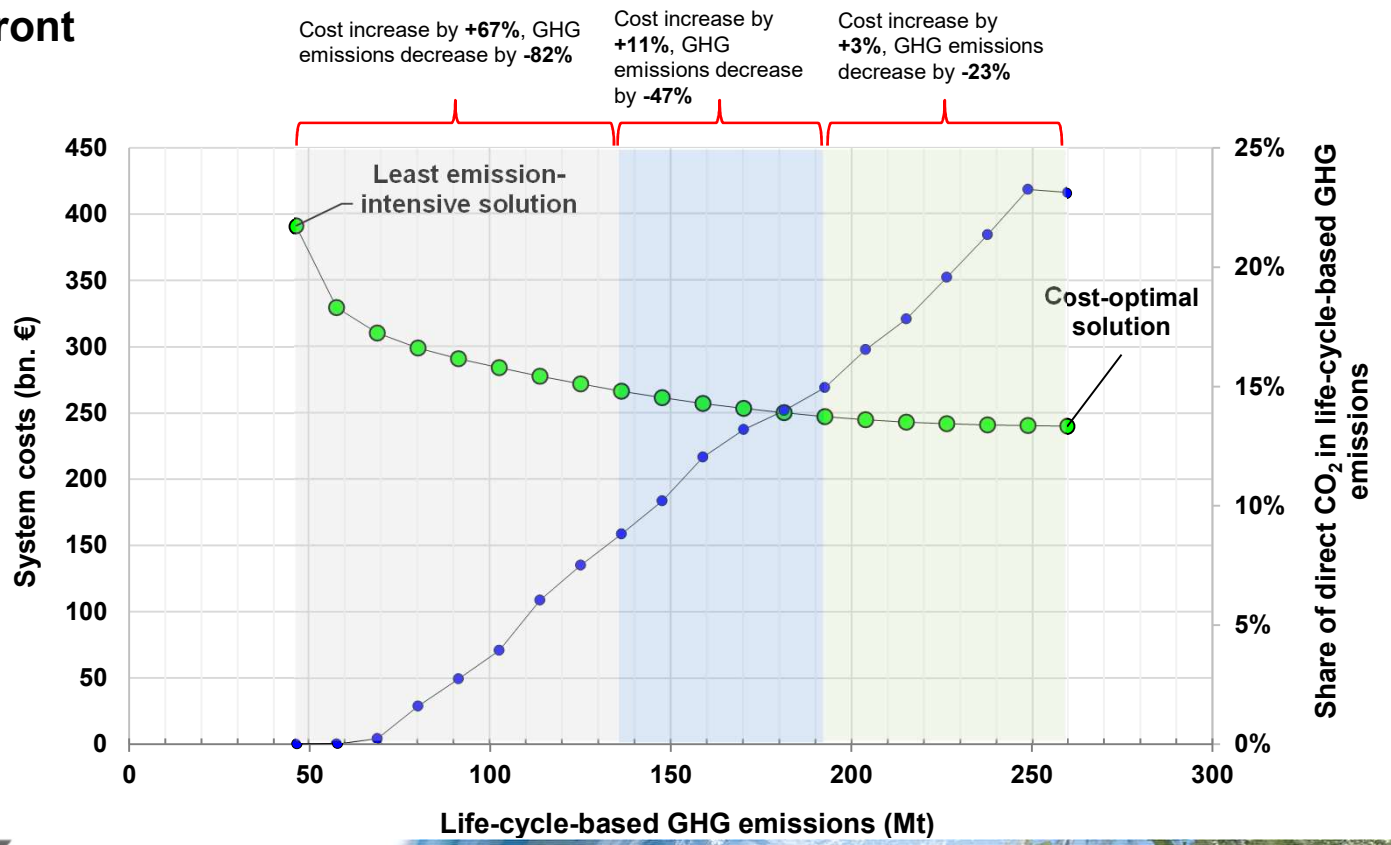
Scenario setup

Key assumptions

- **CO_2 emission reduction targets** on direct emissions of **95%** compared to 1990; Integration of a cap of 60 Mt for the **entire model region**
- **Nuclear power is restricted** to currently installed capacities and projects planned in countries where it is permitted; maximal installable capacities of **131 GW**, most of which can be located in France
- **Distribution of the power and hydrogen generation** capacities across EUNA by setting **country-specific self-supply thresholds** of **80%** in terms of annual demand

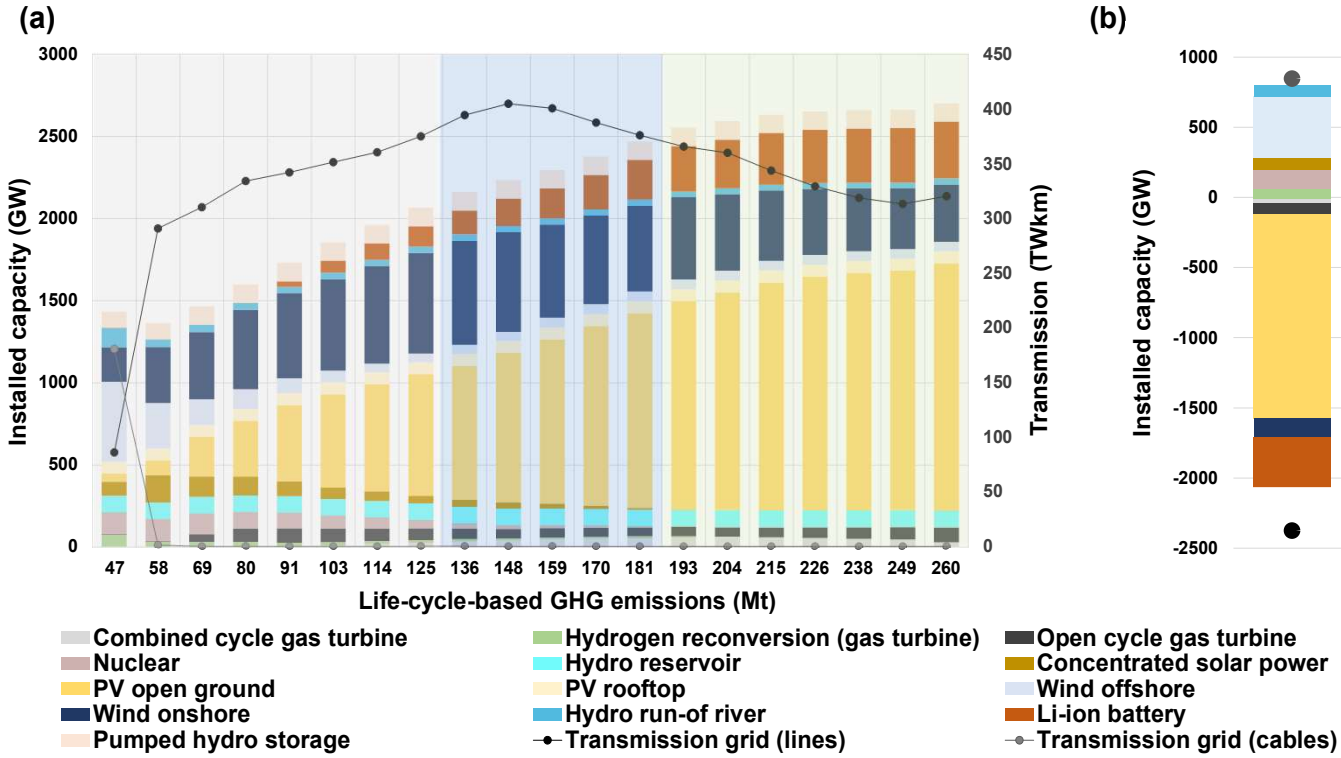


Results
Pareto-front



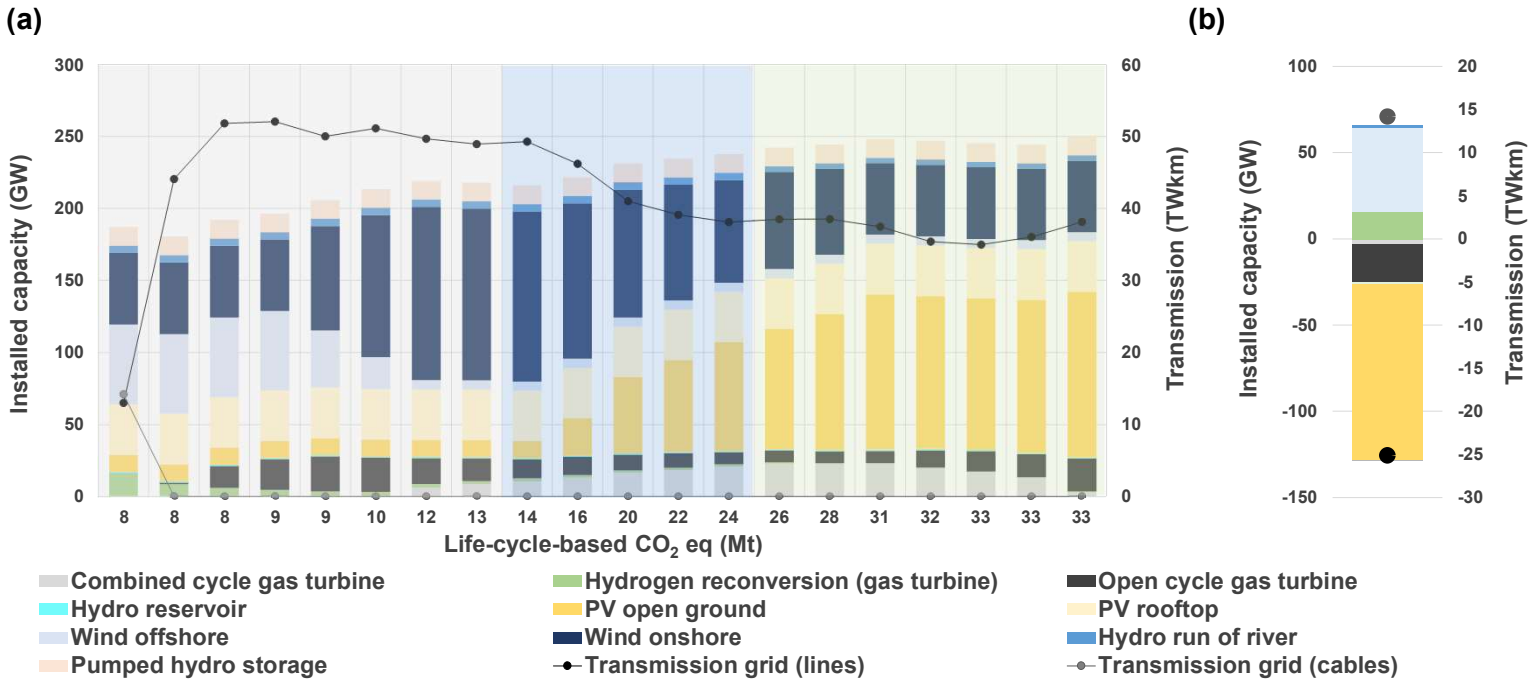
Results

Power generation and electricity grid



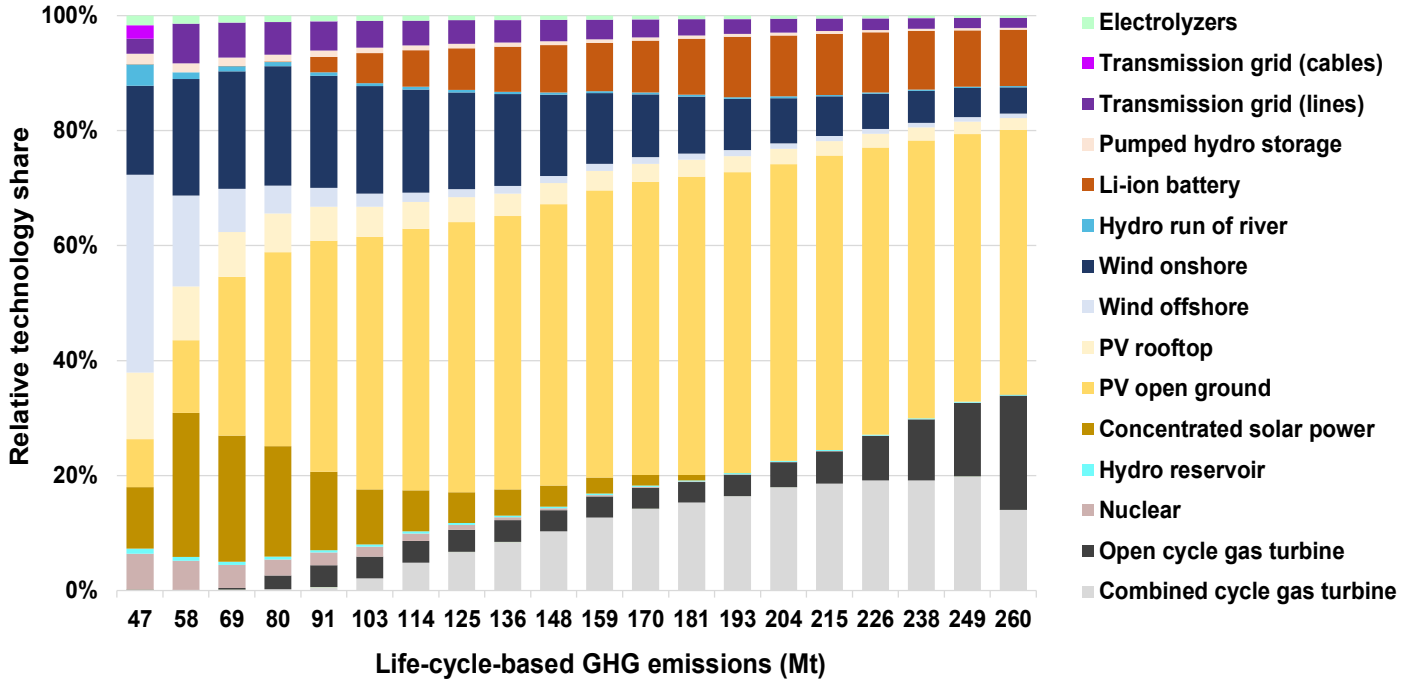
Results

Excursus: Power generation and electricity grid in Germany



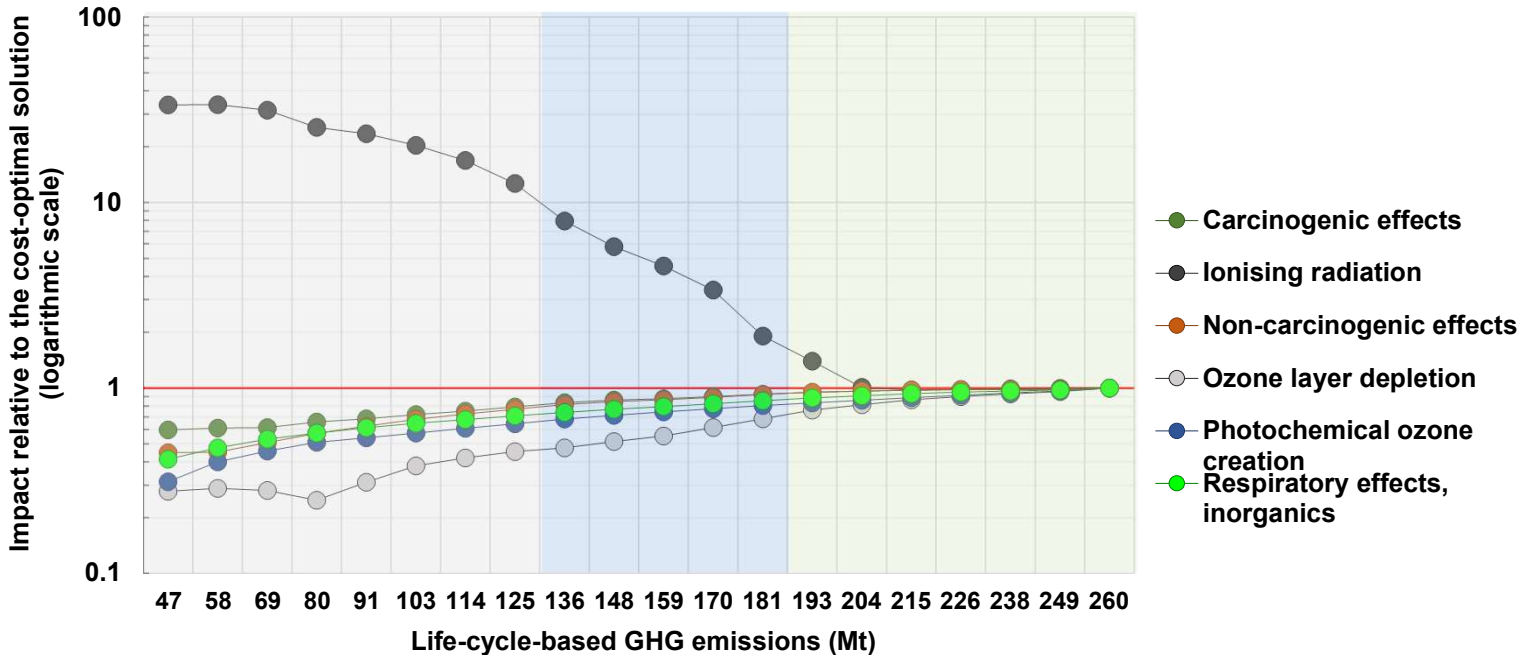
Results

Composition of GHG emissions



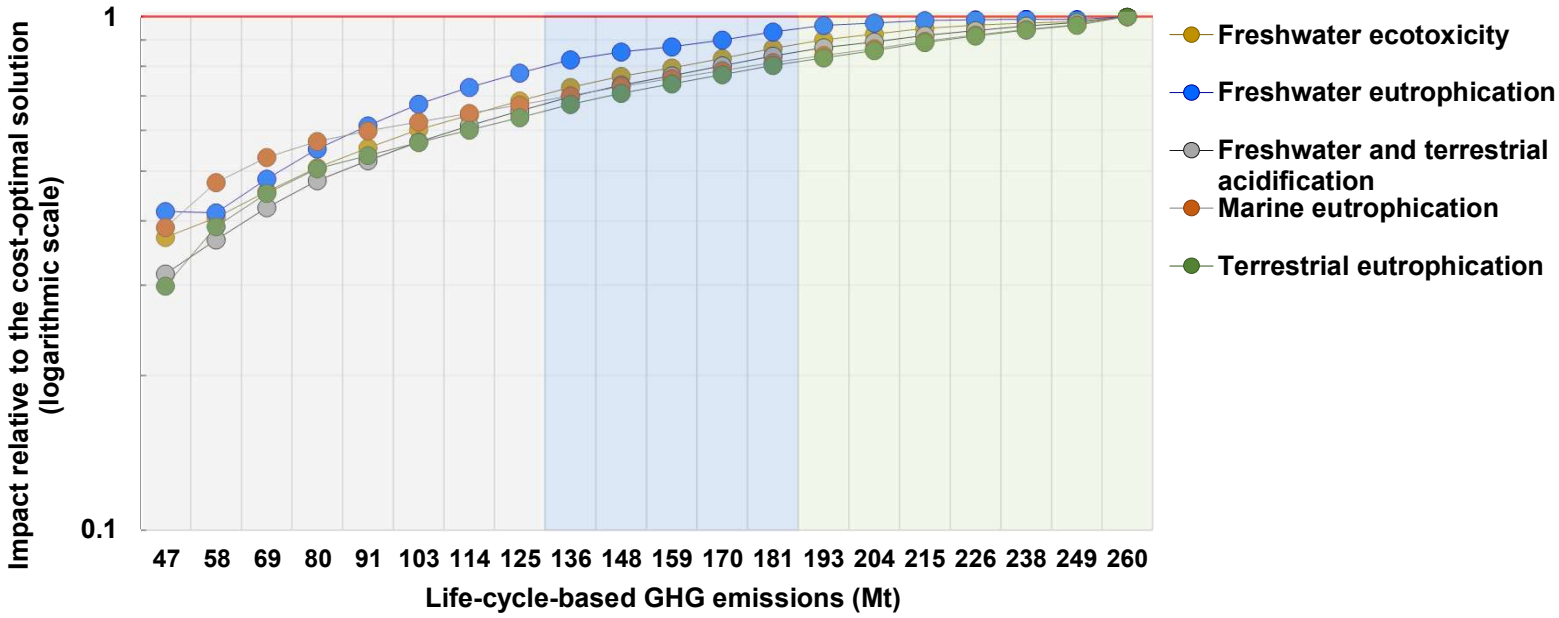
Results

Effects on human health

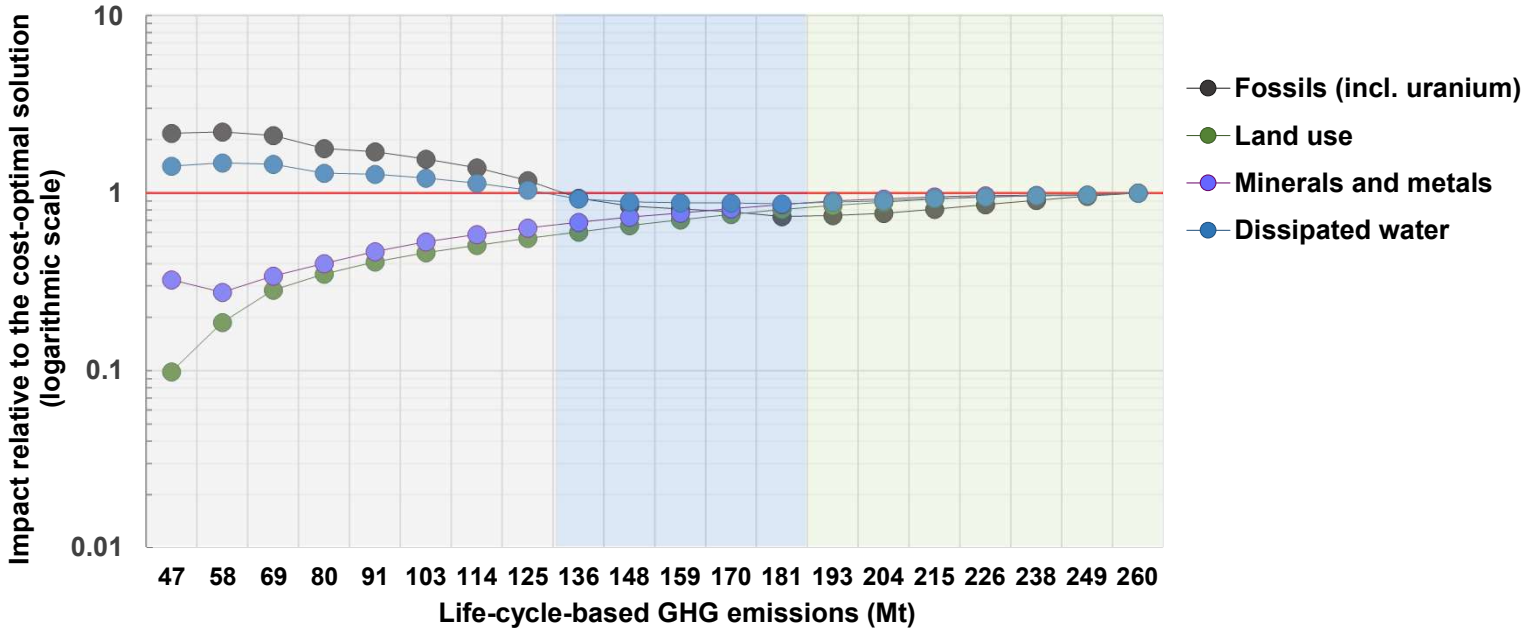


Results

Effects on the ecosystem

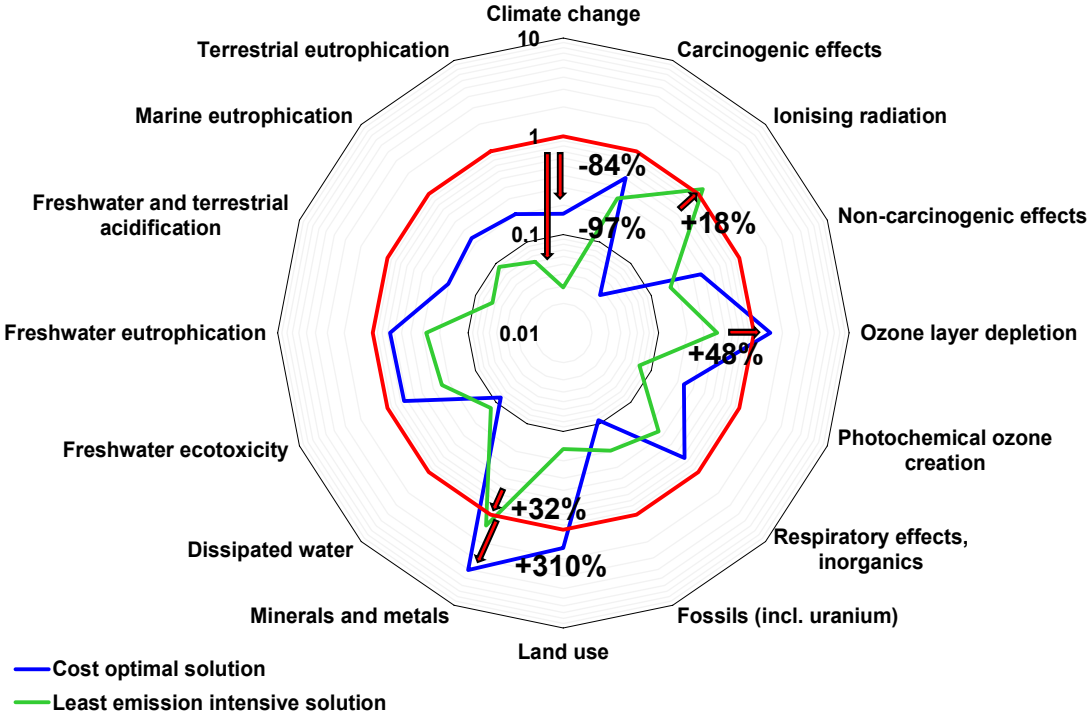


Results
Effects on resources



Results

Comparison with today's electricity mix for Europe



Outlook on future integration approaches

- Limitations to the **LCI data**, indicated in **yesterday's presentation**, are **also present in this work**
  - **However**, **relative differences between technologies** are **decisive in optimization**: if **PV** does not **improve relative to the other technologies** when adjustments are made to fore- and background LCI data, it can be assumed that the **technology mix will remain similar** as shown here and only the absolute level of environmental impact would be affected
  - Need for **inclusion** of further **substitution technologies**
- **Broaden** the **sectoral scope** to assess the **role of cross-sectoral linkages** in reducing LCA emissions for the **entire energy system**
- Simultaneous **consideration of several indicators** (e.g. by increasing the dimensions on the pareto front, weighted objective function, predefined caps, monetization)
- Identify which other **social and economic indicators** would be **suitable** for **model endogenous integration**
- Keep the **large computing** times in mind

Conclusions

- **The first third** of possible life cycle GHG emission avoidance can be achieved with **comparably small increases in total system costs** (compared to the cost-optimal solution for a 95% reduction in direct CO_2 emissions)
- Systems where life cycle GHG emissions are reduced at moderate costs **increasingly** rely on **on-and offshore wind power, grid expansion** with **reduced** shares **of Li-ion batteries and PV**
- **Further reductions** of life-cycle GHG emissions are supported by the deployment of **wind offshore, CSP and nuclear power**; **hydrogen re-conversion** is used to cover demand in **peak load hours**
- **Most categories** are improved in the reduction of life cycle GHG, i.e. they show **co-benefits**, however, **water and uranium use as well as ionizing radiation increases**
  - Note that **other impacts related to nuclear power** such as the **risk of an accident, waste treatment and social acceptance** were **outside the scope** of our assessment

➢ The combination of LCA and ESOMs is of great benefit to both methods and **research** on this topic is still **in its early stages**

Thank you very much for your attention!

Supported by:

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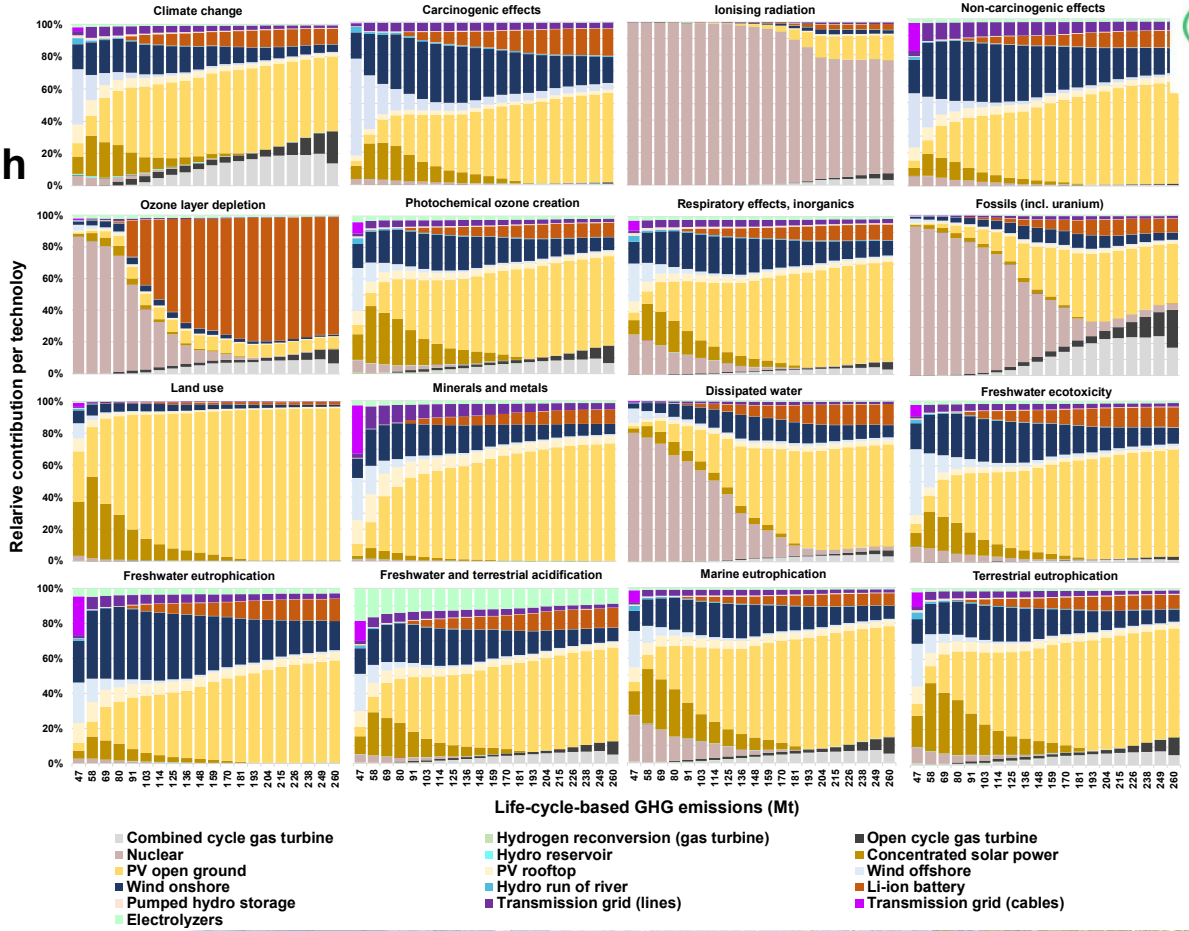
Responsible for the content of this presentation: Tobias Junne, tobias.junne@dlr.de

Back-up

Technology contribution to each impact category



Back-up

Power generation and electricity grid without nuclear power