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Sustainable Power Systems Transformation of Industrial Regions: Insights from Energy System Modelling

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Agenda

- Motivation
- Method
- Power system expansion planning of the Rhenish Mining Area
- Conclusion & Outlook

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Motivation

Considering environmental impacts in Energy System Models

- Consideration of environmental impacts in ESMs: (Direct) CO_2 or greenhouse gas emissions in ESMs, other environmental impacts are often neglected
- Energy systems have large environmental impacts (also besides climate change)
- Direct GHG-emissions are not suitable for comparison among renewable energy technologies
- For renewable energy technologies
  - …environmental impacts shift to other impact categories.
  - …environmental impacts shift from the use phase to the construction phase.

Integrating LCA and ESM

- Endogenisation of Life Cycle Assessment (LCA) in ESM allows…
  - …to perform an **systemic** LCA of the energy system.
  - …to **constrain** environmental impacts as boundary conditions.
  - …to **optimise** environmental impacts as objective functions.
- Thereby, …
  - …investigation of interdependencies and correlations between costs and different environmental impacts is possible.
  - …multiple impact categories (or costs) can be used as objectives to calculate multi-objective Pareto fronts.
  - …efficient (i.e. Pareto-optimal) decisions are facilitated.

Method

Integrating Life Cycle Assessment in Backbone

- Energy System Optimisation Framework Backbone[1]
- New parameters for environmental impacts from investments (construction phase) & outputs of units (use phase)
- New equations for environmental impacts to be used as constraints & objective functions
  - Multi objective energy system optimization (augmented epsilon-constraint method[2])

$$v_i^{\text{envImpact}} = \sum_{\substack{\text{nodes}\, n,\\ \text{units}\, u}} \left(\underbrace{p_{n,u,i}^{\text{construction}} \cdot p_{n,u,i}^{\text{constructionShare}} \cdot v_{n,u}^{\text{investedCapacity}}}_{\text{Construction phase}} + \sum_{\text{time}\, t} \underbrace{p_{n,u,i}^{\text{usePhase}} \cdot v_{n,u,t}^{\text{generation}}}_{\text{Use phase}} \right)$$

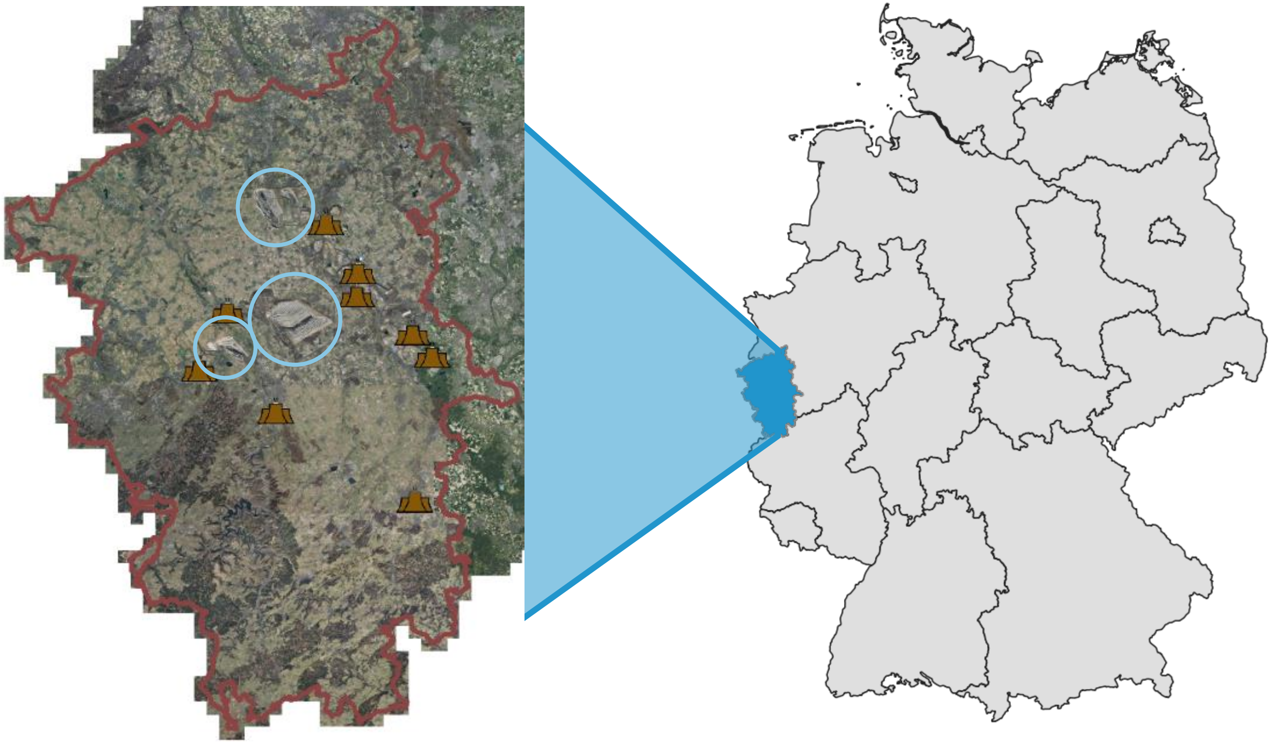
with parameters p, variables v, impact categories i

[1] Helistö et al., *Backbone – An Adaptable Energy Systems Modelling Framework*, Energies 2019.

[2] Finke & Bertsch, *Implementing a highly adaptable method for the multi-objective optimisation of energy systems*, Applied Energy, 2023

Power system expansion planning of the Rhenish Mining Area

The Rhenish Mining Area



Aerial picture: https://www.energieatlas.nrw.de/site/planungskarten/rheinisches_revier

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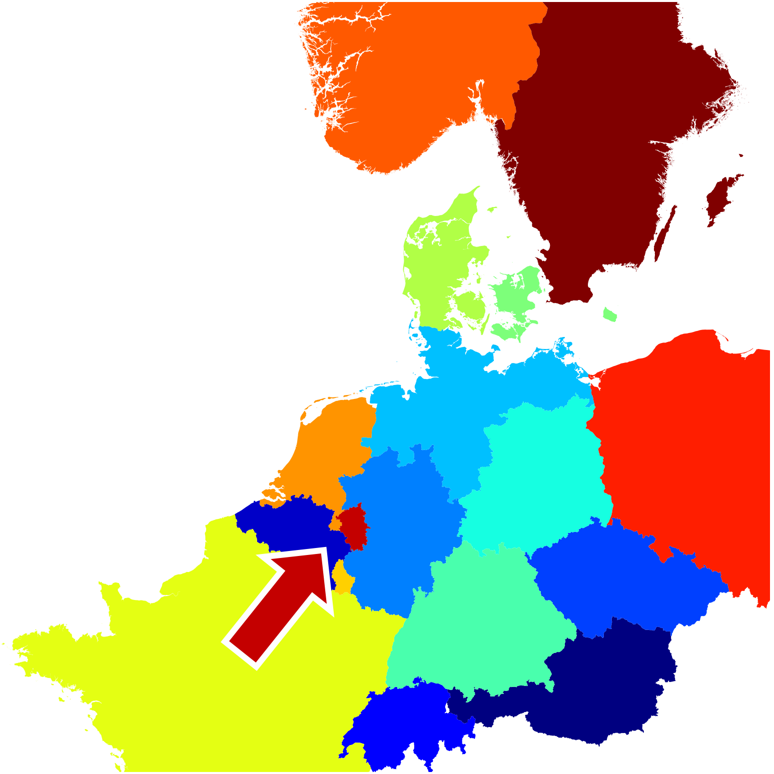
The Rhenish Mining Area



- High concentration of lignite-fired power plants that will be shut down until 2030

  → Region of significant structural change

- Spatial resolution
  - Germany (RMA and four nodes)
  - Neigbouring countries, Sweden and Norway

- Target year 2040, after the German nuclear- and coal-exit

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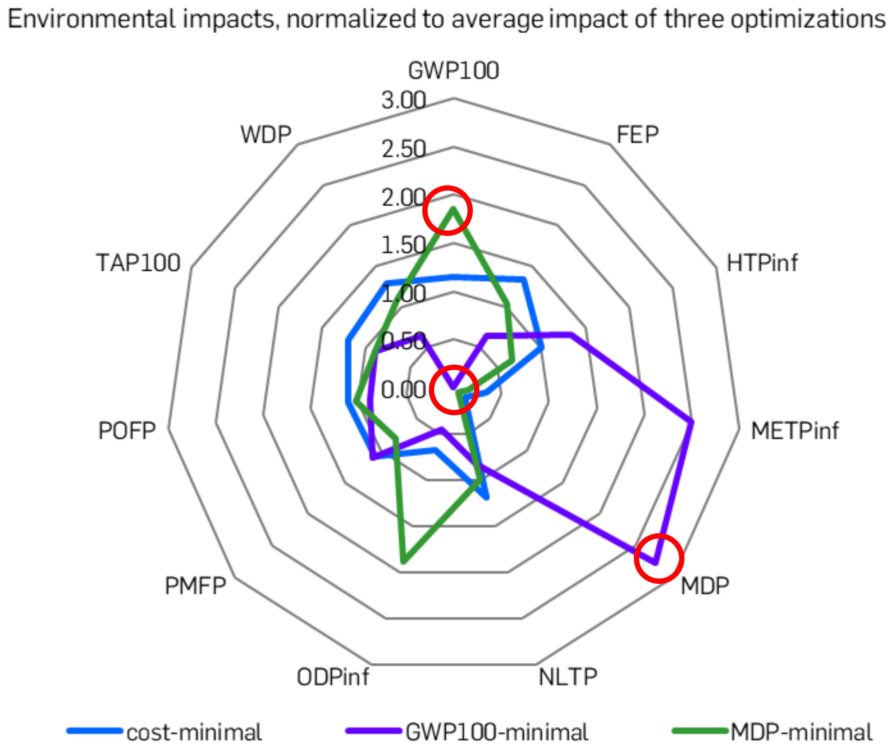
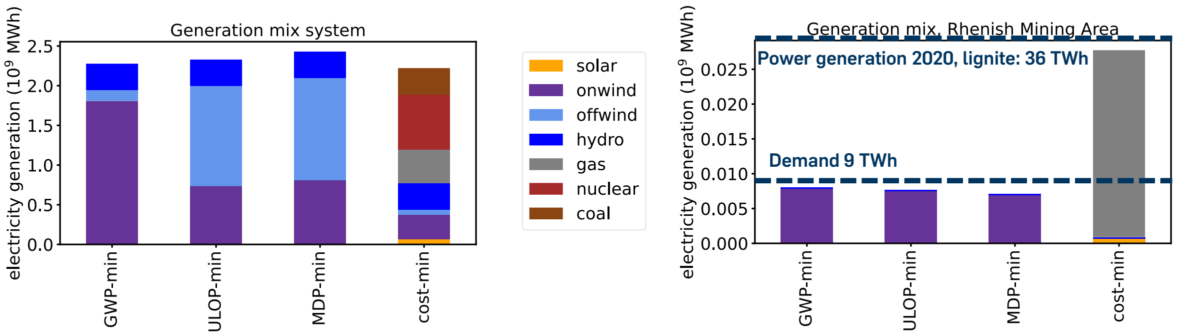
Environmental impacts of the complete ES with different objectives



- Conflicting objectives: GWP and MDP

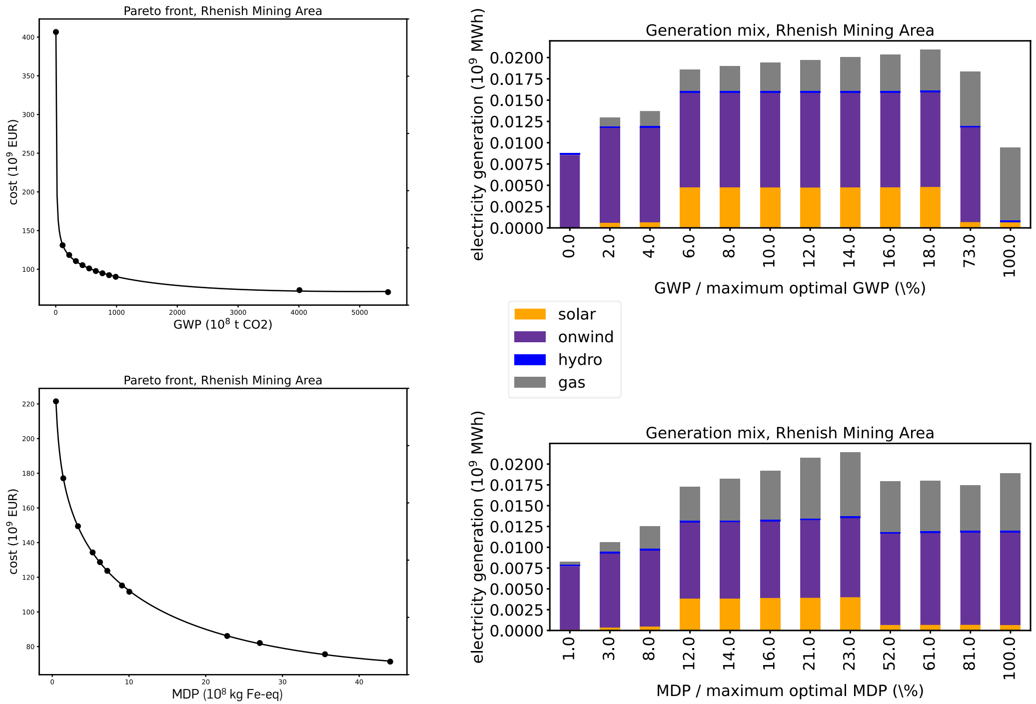
GWP100 – climate change
FEP – freshwater eutrophication
HTPinf – human toxicity
METPinf – marine ecotoxicity
MDP – metal depletion
NLTP – natural land transformation
ODPinf – ozone depletion
PMFP – particulate matter formation
MOFP – photochemical oxidant formation
TAP100 – terrestrial acidification
WDP – water depletion

Individual optimization of four objectives



- Preferences
  - hydro- and wind power for all env. objectives
- Significantly lower generation in the RMA

Multi-objective optimization for cost and environmental impacts



- Maximum optimal system costs are lower for MDP than GWP
- Generation mix of onshore wind, gas, solar and hydropower
- Similar technology shares and overall generation for different env. objectives

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Conclusion & Outlook

Conclusion & Outlook

- Implemented method enables for energy systems to…
  - …perform a systemic LCA.
  - …optimise and constrain environmental impacts.
  - …optimise system costs and an environmental impact simultanously.

- Application reveals synergies and conflicts between objectives
- Energy systems differ substantially for different optimisation objectives

Future work

- Sector-coupled systems, i.e. steel and cement production
- Prospective LCA

Thank you very much!

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