Coherent Transformation Pathways in Energy System Modeling – A Case Study for Germany

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Energy Economics and Technology

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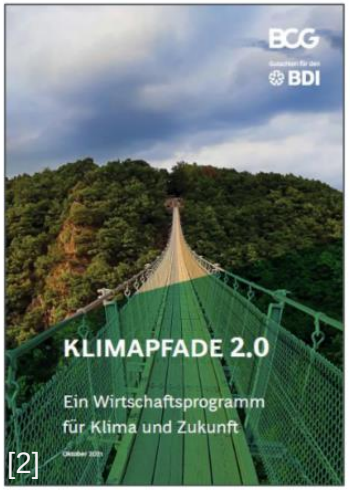
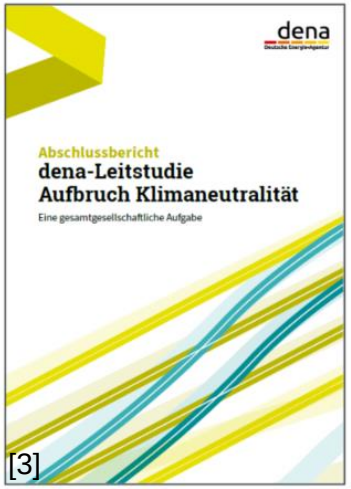
IEK-3: Institute of Techno-economic Systems Analysis

Motivation

[1]



[2]



[3]

[4]

[5]

- Spatially resolved analysis of infrastructures (generation + transmission) often neglected in energy system studies
- Research question:
  - How would the spatial distribution of generation and transmission infrastructures develop in an energy system taking hydrogen into account?

Features of this work:

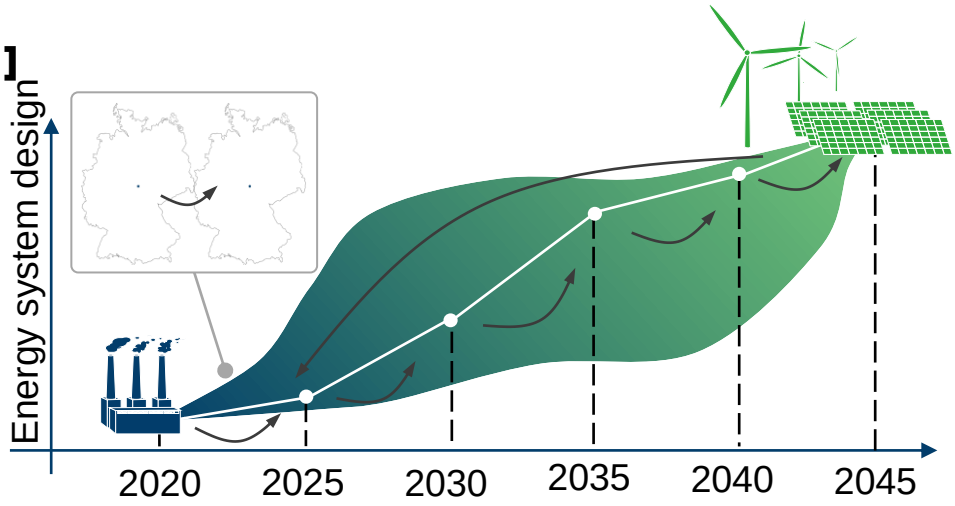
- **Integrated** energy system model: Greenhouse gas neutral Germany 2045
- **Transmission** infrastructures with the **focus on hydrogen**
- **Transformation pathways** (2020-2045) with and without **inheritance** of infrastructure components

[1] Agora Energiewende. Klimaneutrales Deutschland 2045: Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann; 2021.
[2] BGC, BDI. Klimapfade 2.0: Ein Wirtschaftsprogramm für Klima und Zukunft; 2021.
[3] Jugel C, Albicker M. dena-Leitstudie Aufbruch Klimaneutralität: Eine gesamtgesellschaftliche Aufgabe; 2021.
[4] Sensfuss F, Sensfuß F, Lux B, Bernath C, Kiefer C, Pfluger B, et al. Langfristszenarien für die Transformation des Energiesystems in Deutschland 3: Kurzbericht: 3 Hauptszenarien; 2021.
[5] Luderer G, Kost C, Dominika. Deutschland auf dem Weg zur Klimaneutralität 2045: Szenarien und Pfade im Modellvergleich: Potsdam Institute for Climate Impact Research; 2021.

Methodology: Model Coupling

ETHOS.NESTOR [1]
Single-region model

Myopic Transformation Solution Space



Specs of the optimization

- Integrated energy system model
- Minimizing total annual costs (TAC)
- Hourly resolution (8760 time steps)
- Myopic transformation
- **Scenario**: Greenhouse gas neutral transformation for Germany 2020-2045
- **Commodities**: electricity, methane, hydrogen, heat
- **Sectors**: industry, transport, energy, households, CTS
- **Single-region model**: High sectoral coverage
- **Multi-region model**: High spatial resolution (80 regions)

[1] Kullmann F, Markewitz P, Kotzur L, Stolten D. The value of recycling for low-carbon energy systems - A case study of Germany's energy transition. Energy. 2022;256:124660. doi:10.1016/j.energy.2022.124660.

[2] Groß T. Multiregionales Energiesystemmodell mit Fokus auf Infrastrukturen: RWTH Aachen University; 2023.

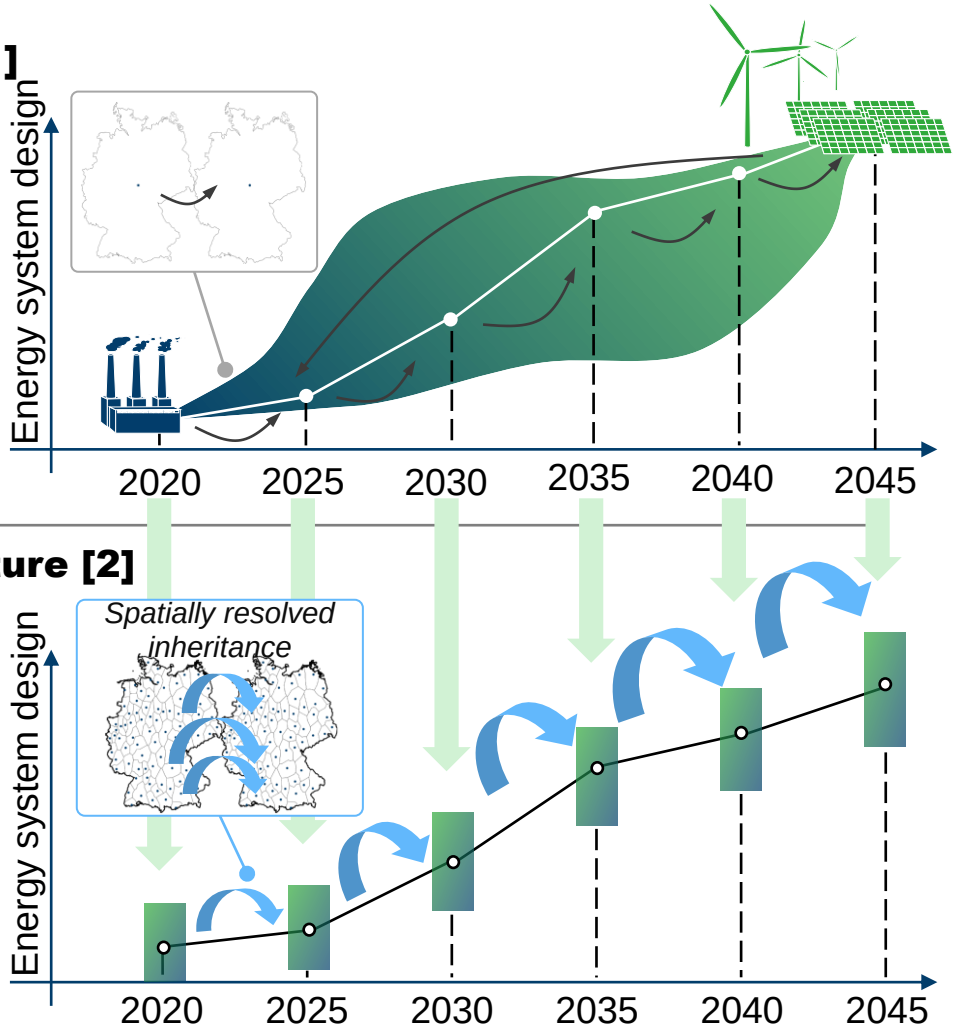
Methodology: Model Coupling

ETHOS.NESTOR [1]
Single-region model

Myopic Transformation Solution Space

ETHOS.Infrastructure [2]
Multi-region model

Model Coupling
Inheritance
Solution Space



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Scheme of the Model Coupling Between the Singe- and Multi-Region Model

ETHOS.NESTOR
Single-region model

optimization

Subset of the ETHOS.NESTOR results [1]

ETHOS.Infrastructure
Multi-region model

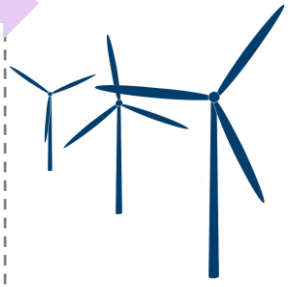
Model coupling [2]

Total import quantities

Total capacities of selected energy sources and conversion units

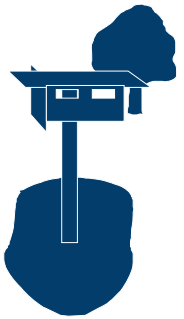
Regionalized demand profiles

Conversion and energy sources



Storage

Transmission



Import

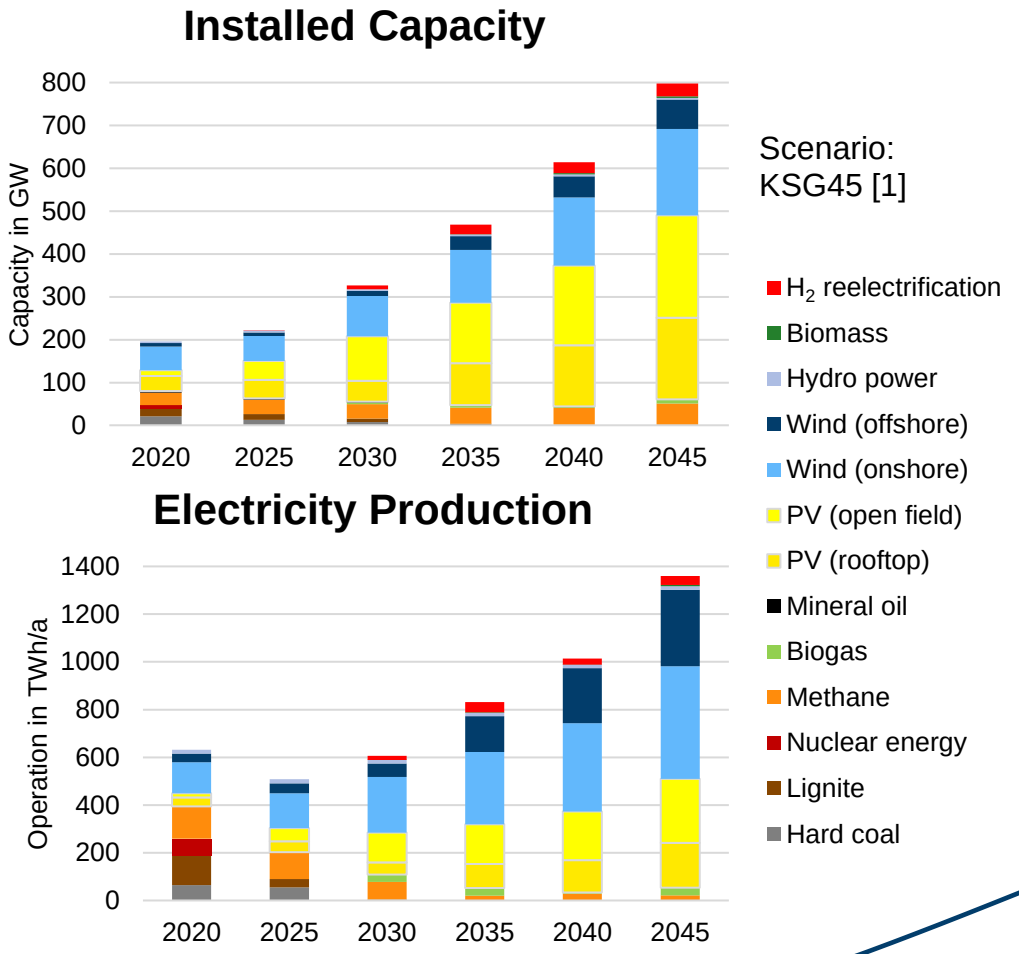
Demand

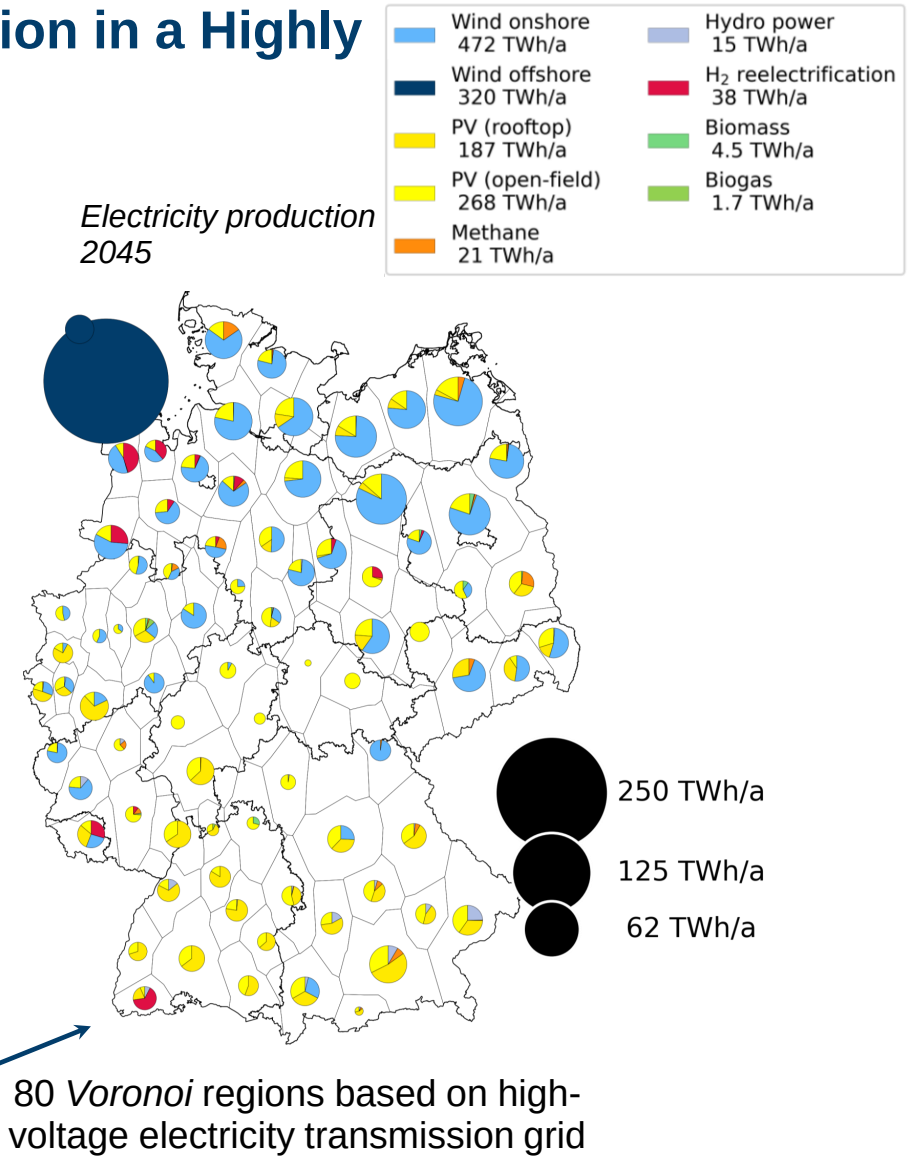
Export

Legend
Data/information flow
Energy/material flow
Process flow

[1] Figure adapted from: Busch T, Groß T, Linßen J, Stolten D. The Role of Liquid Hydrogen in Integrated Energy Systems—A Case Study for Germany. International Journal of Hydrogen Energy. 2023 (under review).
[2] Groß T. Multiregionales Energiesystemmodell mit Fokus auf Infrastrukturen: RWTH Aachen University; 2023.

Spatial Distribution of Electricity Production in a Highly Resolved Energy System Model



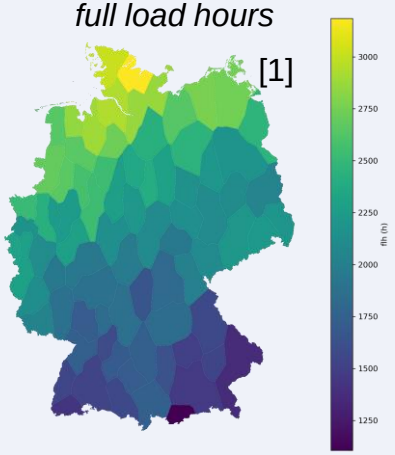


[1] Stolten D, Markewitz P, Schöb T, Kullmann F, Kotzur, L. et al. New targets using old pathways?: Strategies for a greenhouse gas neutral energy supply by 2045.

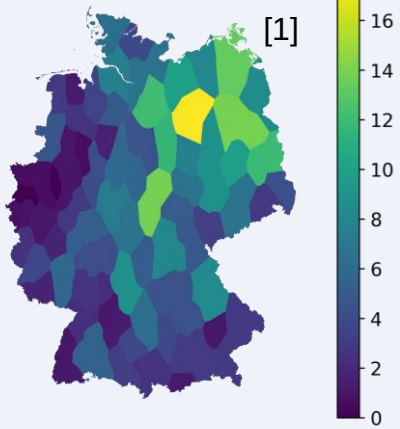
Wind Onshore: Placement in the North and North-East due to High FLH and Land Eligibility

Inputs

full load hours [1]

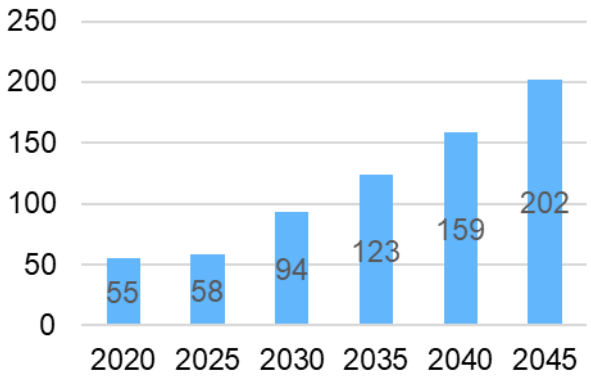


max potential [1]

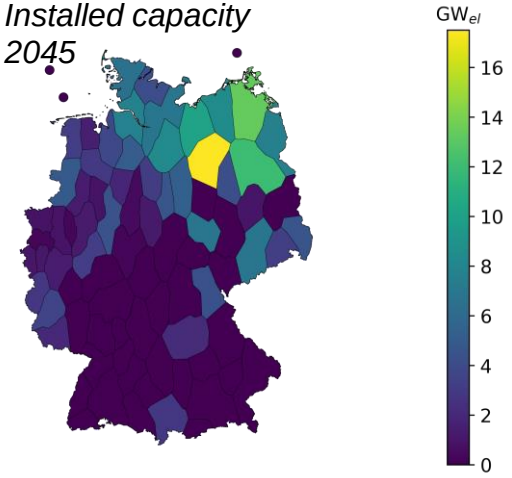


Results

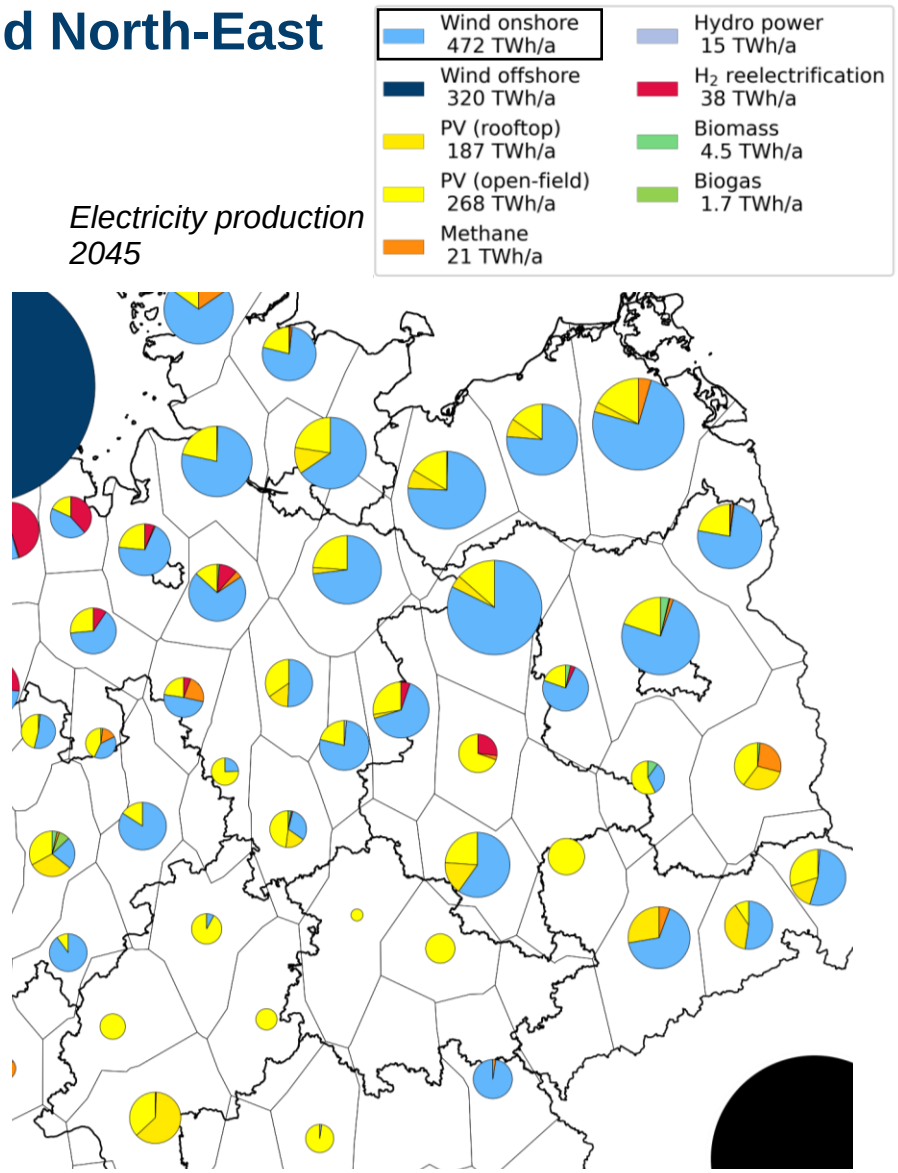
Installed capacity 2020-2045



Installed capacity 2045

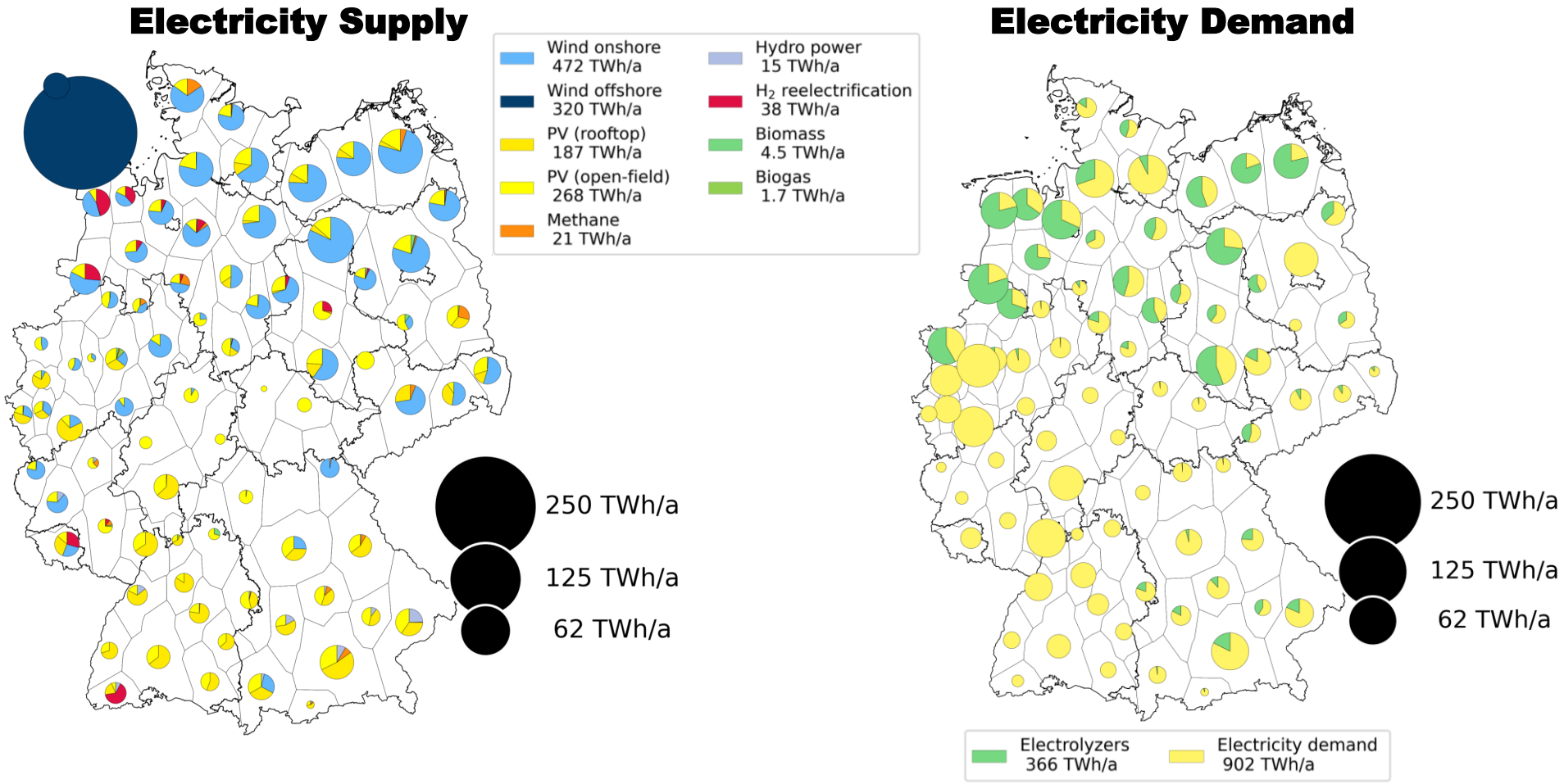


Electricity production 2045



[1] Risch S, Maier R, Du J, Pflugradt N, Stenzel P, Kotzur L, Stolten D. Potentials of Renewable Energy Sources in Germany and the Influence of Land Use Datasets. Energies. 2022;15:5536. doi:10.3390/en15155536.

Placement of Electrolyzers Close to Favourable Renewable Energy Production Sites (Mainly Wind Energy) in the North



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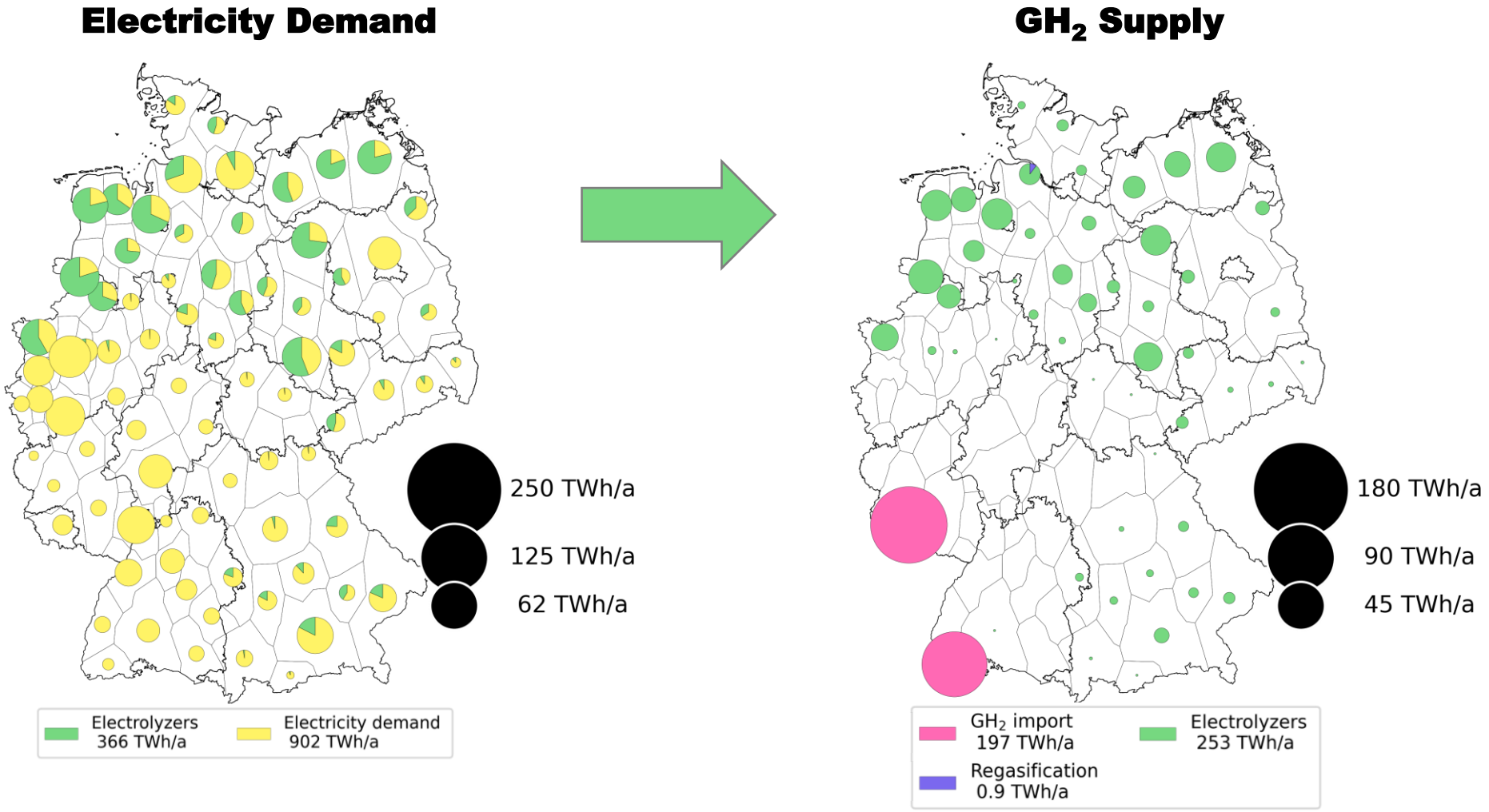
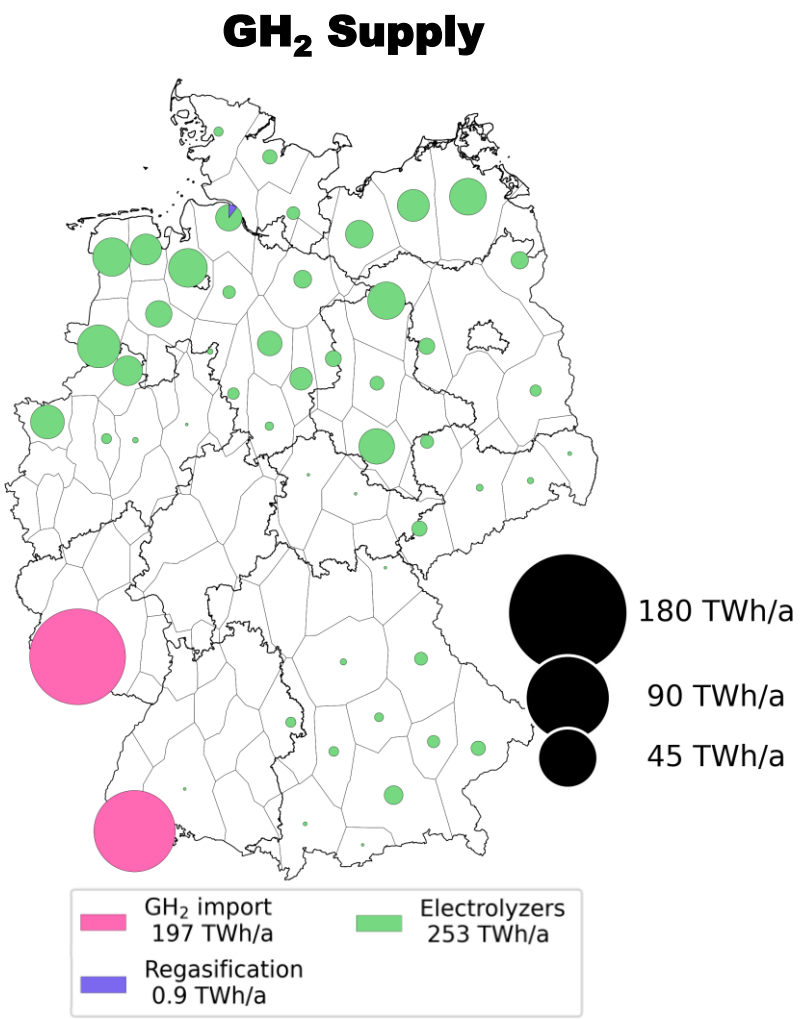
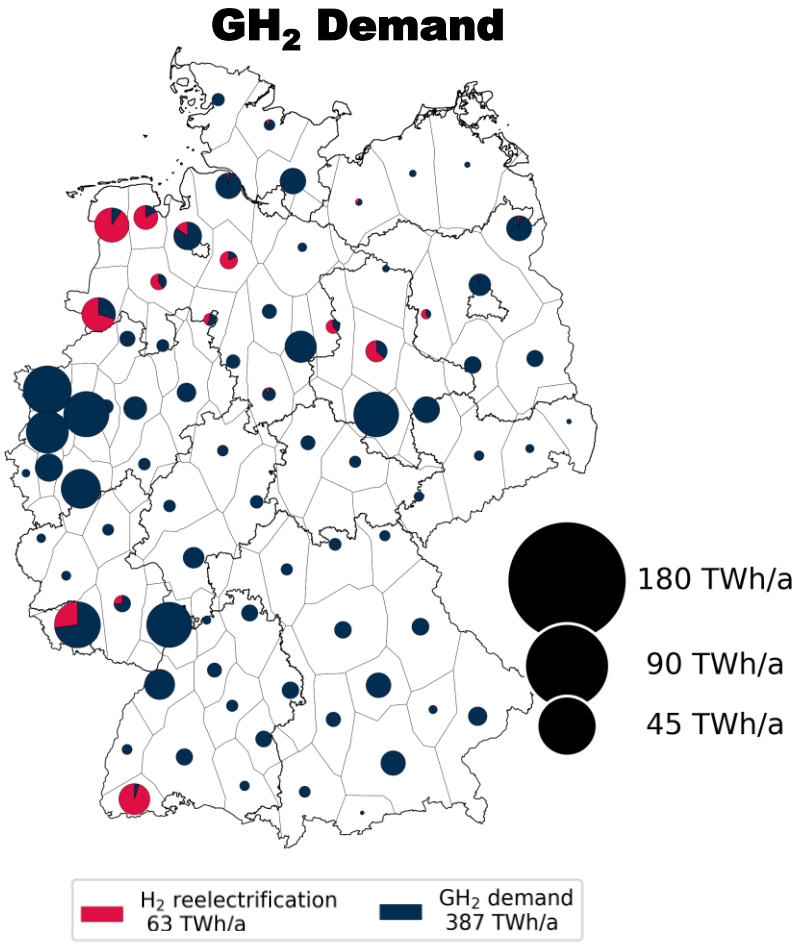
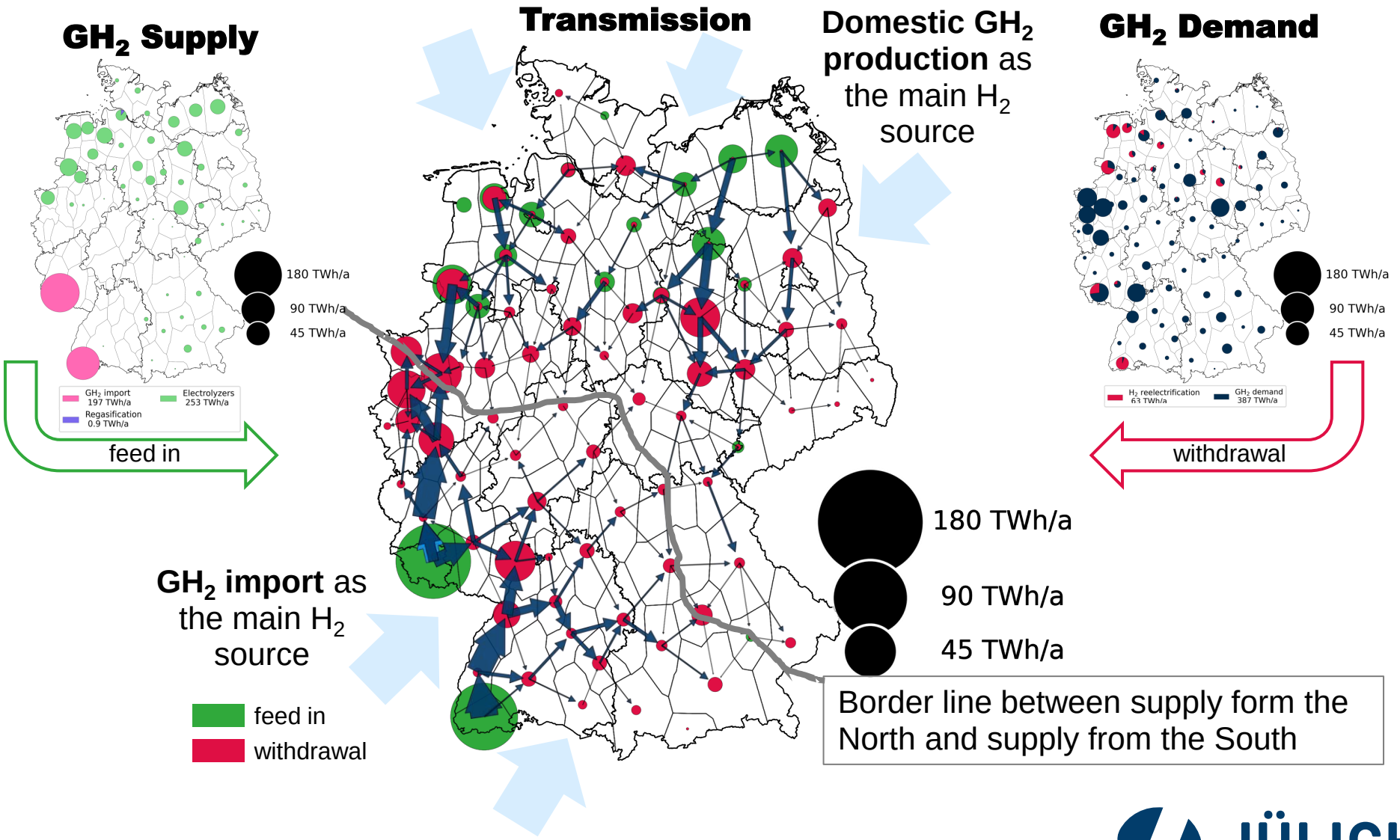


Supply and Demand of Hydrogen do not Fall Together Highlighting the Importance of Transmission Infrastructures





Endogenous Optimization of a Hydrogen Transportation Network based on Supply and Demand



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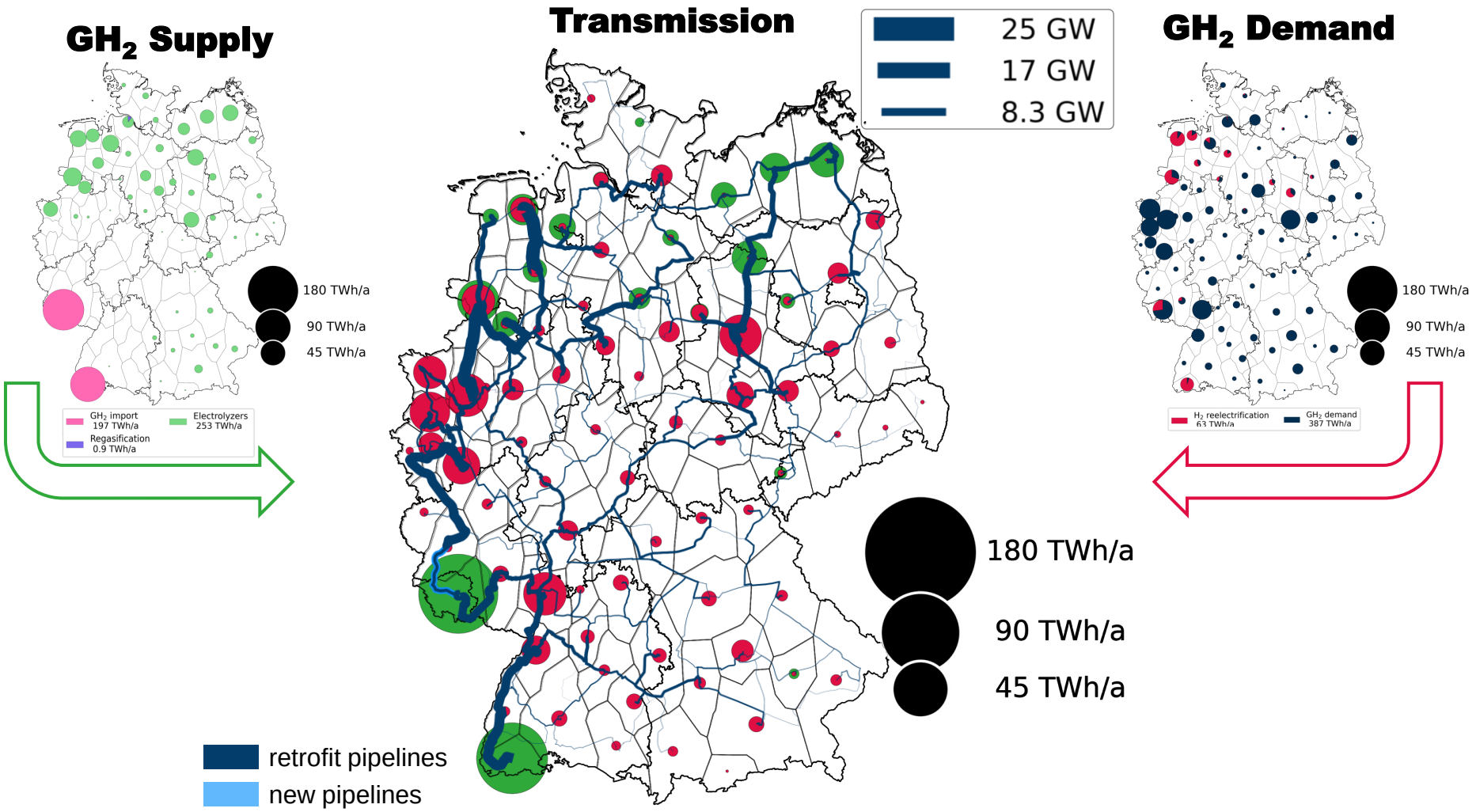
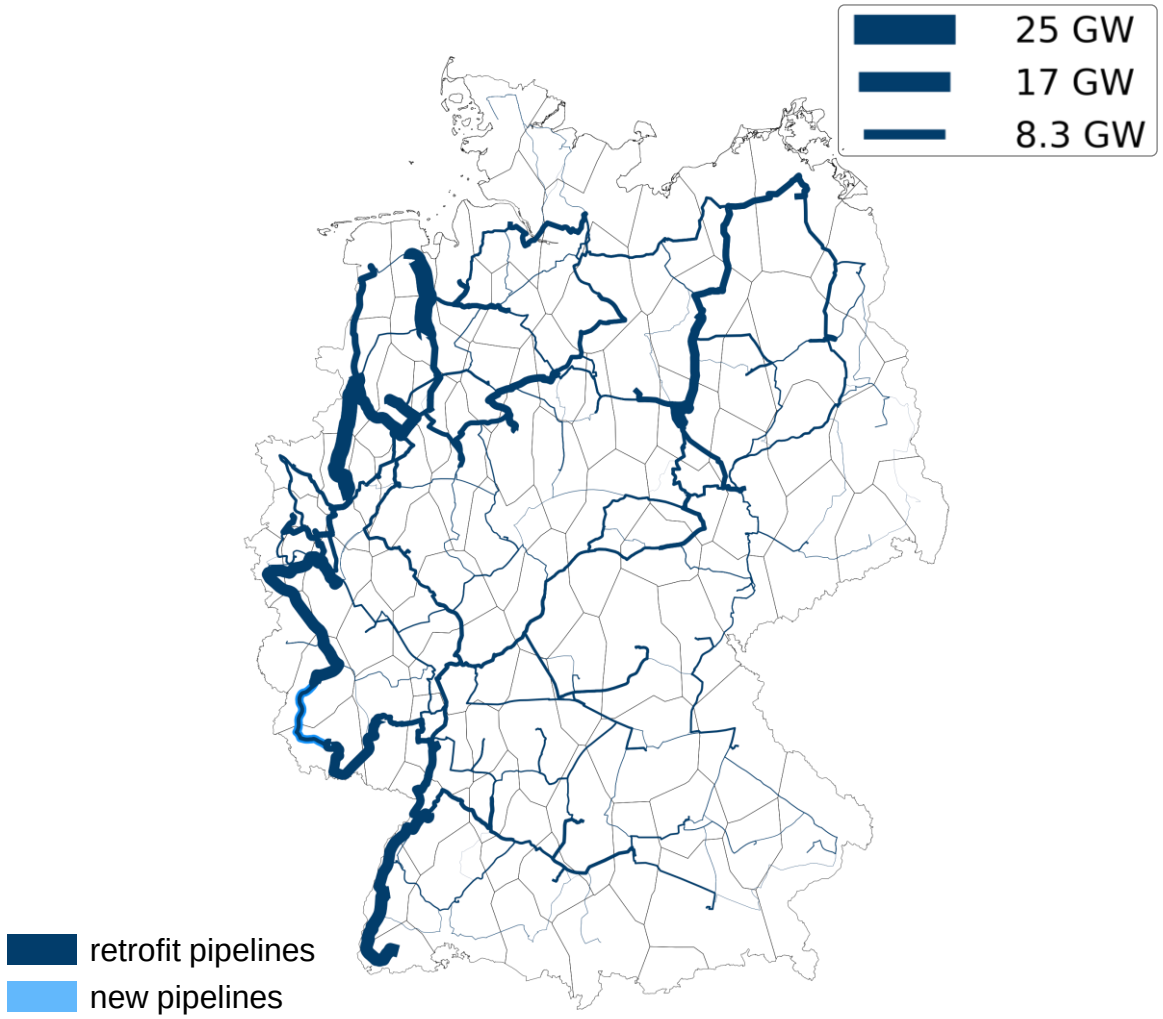


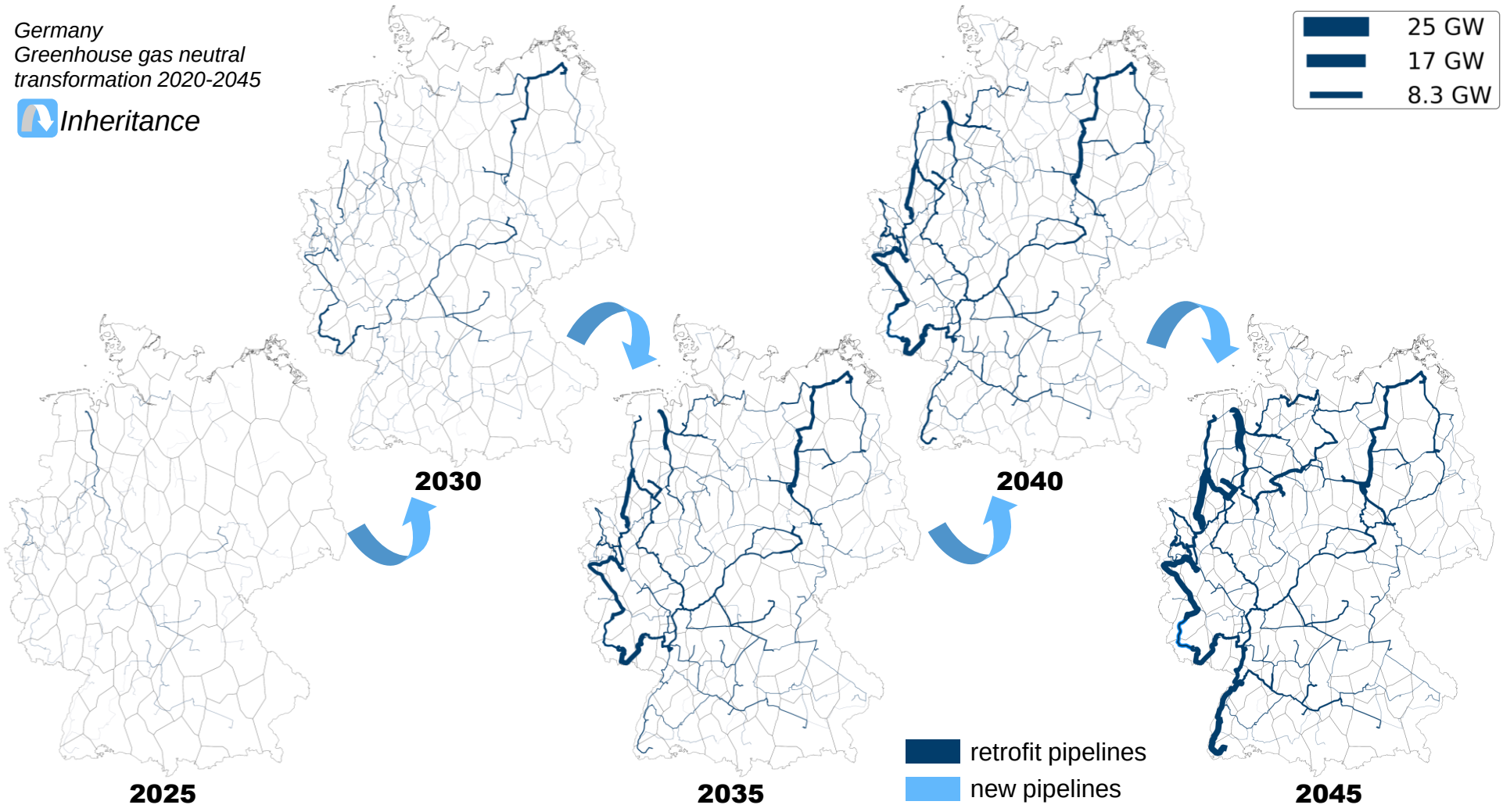
Hydrogen Pipeline Grid 2045



Development of the GH_2 Pipeline Grid Network in an Energy System Model *with* inheritance

Germany
Greenhouse gas neutral transformation 2020-2045

Inheritance



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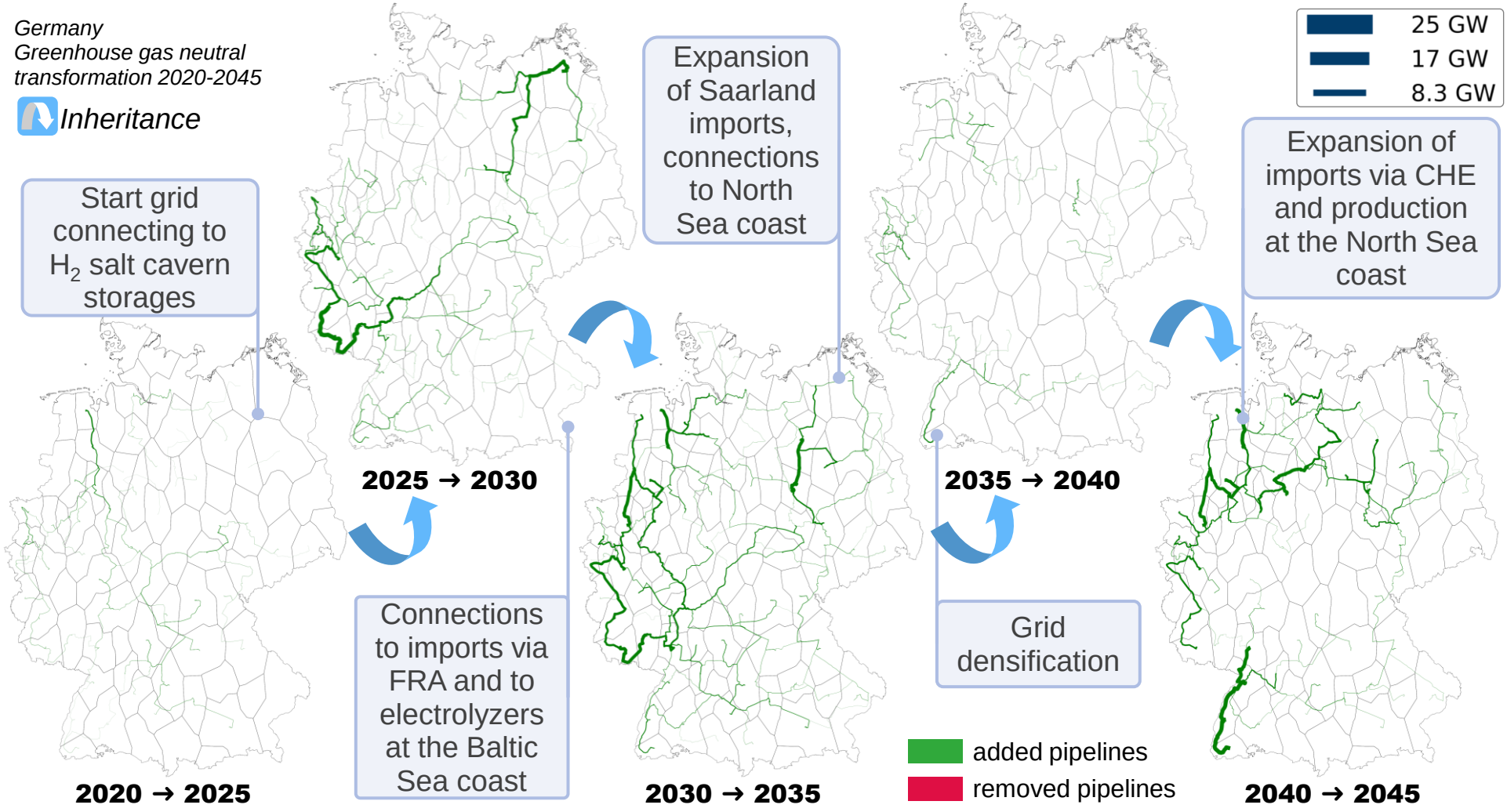

Development of the GH_2 Pipeline Grid Network in an Energy System Model *without* Inheritance

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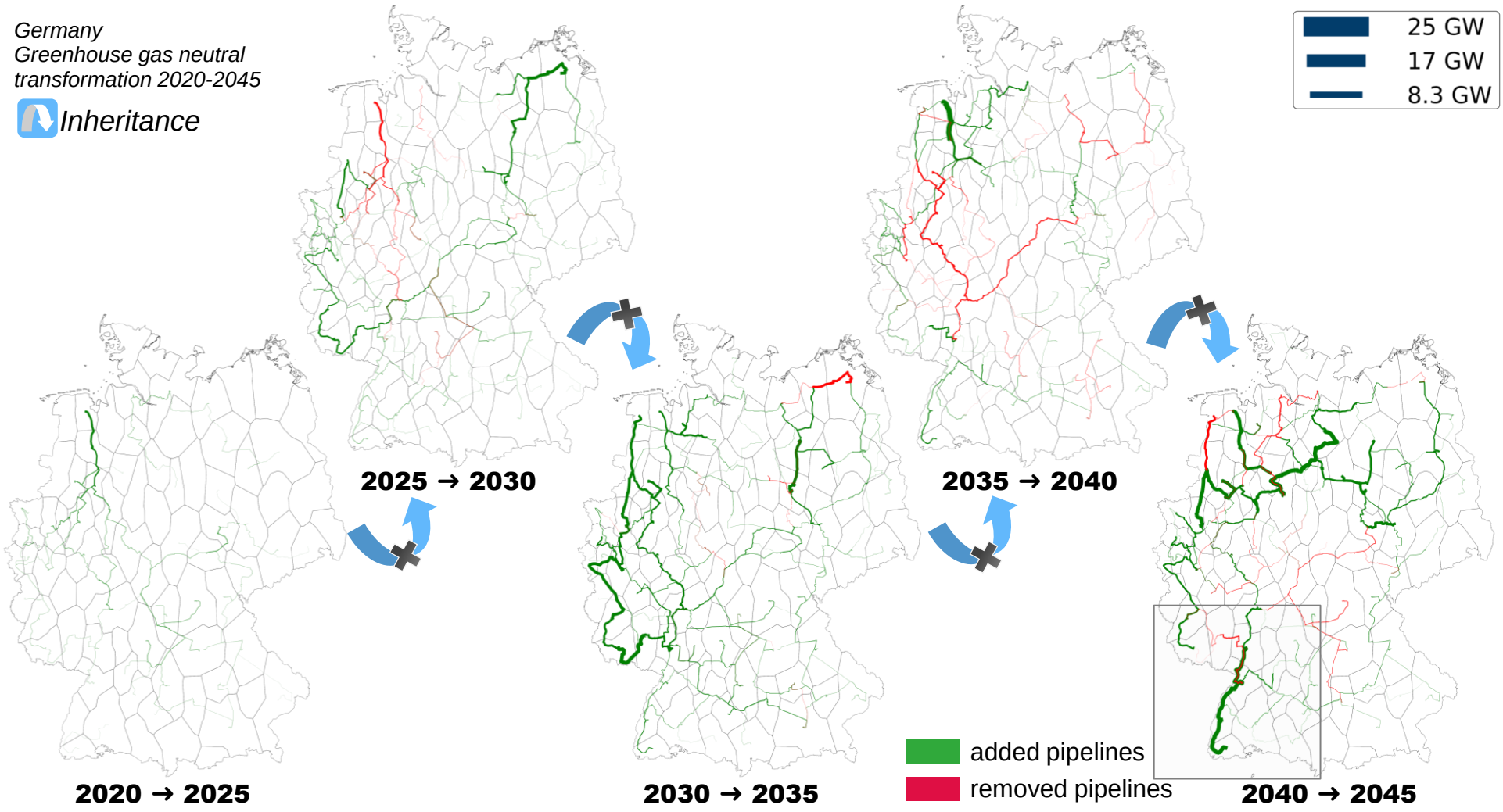
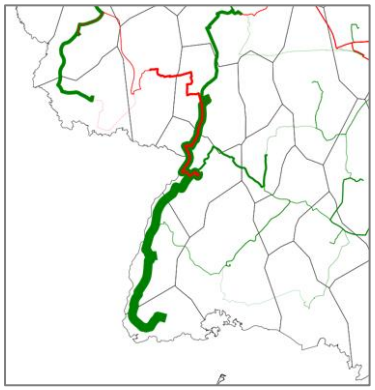
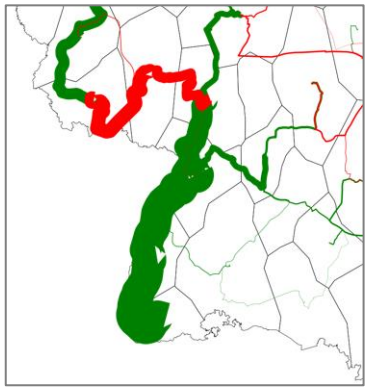


Import Limits in One Region Evoke the Construction of New Import Routes – Old Connection Becomes Obsolete

2040 ➜ 2045
capacity delta
hydrogen grid

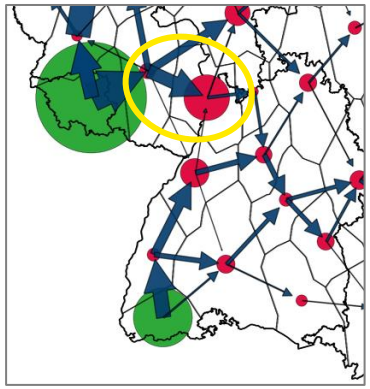


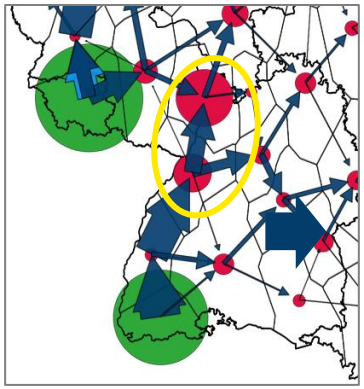


2040 ➜ 2045
operation delta
hydrogen grid

Supply of a region from another direction/source:
- 2040 import from the direction of FRA
- 2045 import from the direction of CHE

2040
operation total
hydrogen flow

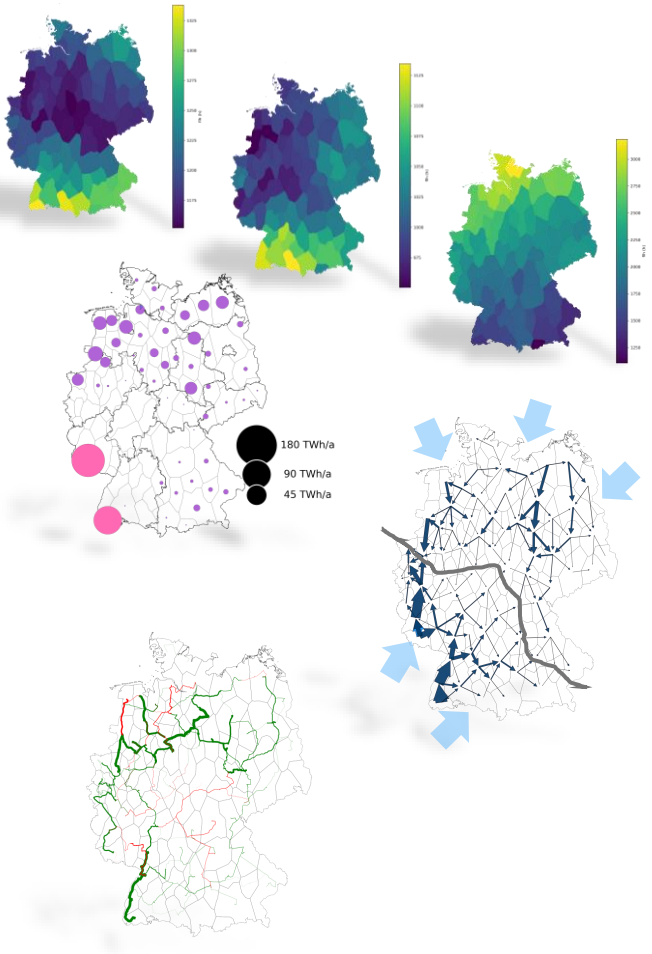




2045
operation total
hydrogen flow

Key Takeaways

- The spatial distribution of renewable energy sources is predominantly determined by **favourable production sites** (high full load hours) if there are suitable **transport** networks
- Hydrogen is provided by **imports** from southern Germany and **domestic** production mainly by wind-powered electrolyzes in northern Germany
- This shows the **importance** of considering **transmission** infrastructures and **integrated** energy system planning
- The **inheritance** of infrastructures in myopic energy system models is a prerequisite for **coherent** transformation pathways and a more realistic expansion of infrastructures
- However, single year optimizations without inheritance can show alternative solutions with **cost optimal** results in **intermediate** years



Thank you for your attention!

For further questions, please contact:

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