Martin Lieberwirth

MODEZEEN – Closing Workshop

Decarbonizing the Industry Sector and its Effect on Electricity Transmission Grid Operation – Implications from a Model Based Analysis for Germany

28. November 2023

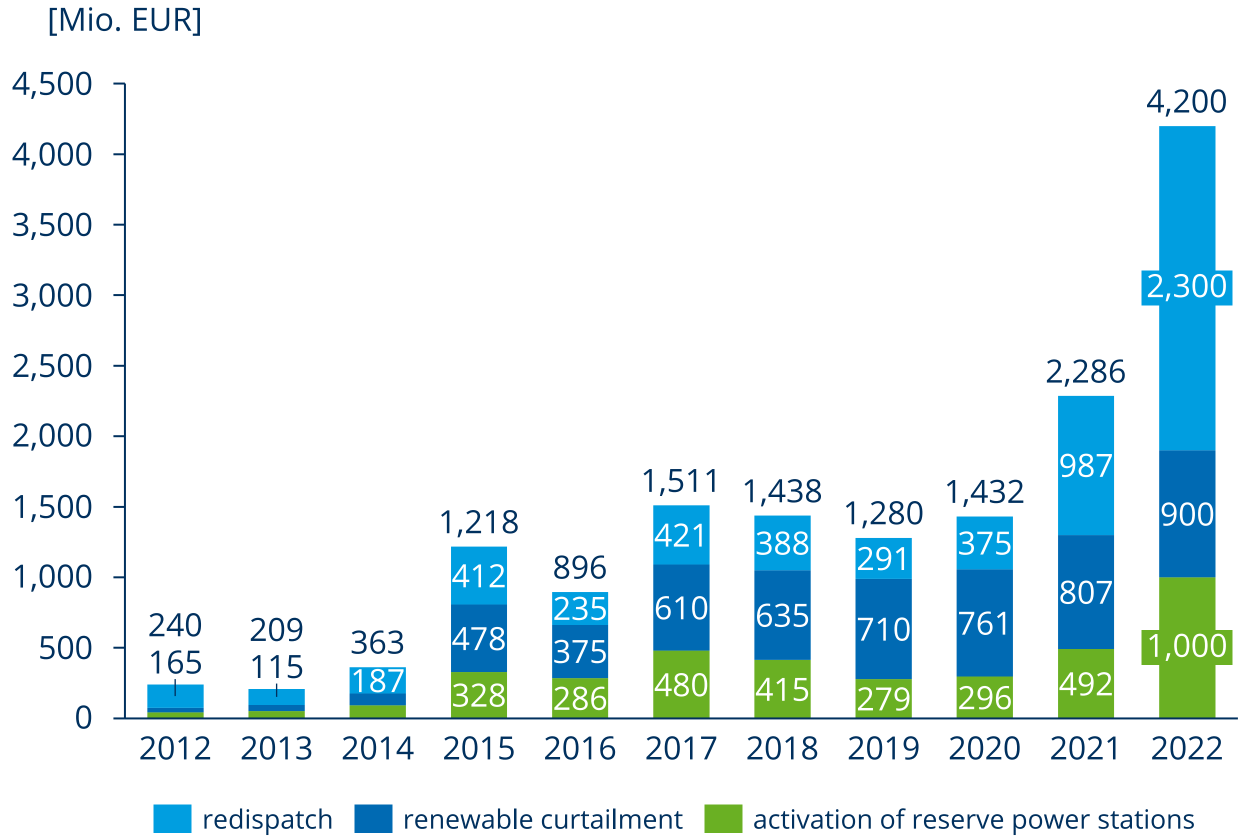
Agenda for today...

- Possible Impact of Electrolyser Operation on Congestion Management
1. Modeling Congestion Management with ELTRAMOD/ELMOD
2. Data and Scenario Framework for a 2030 Projection
3. Scenario Results and Conclusion

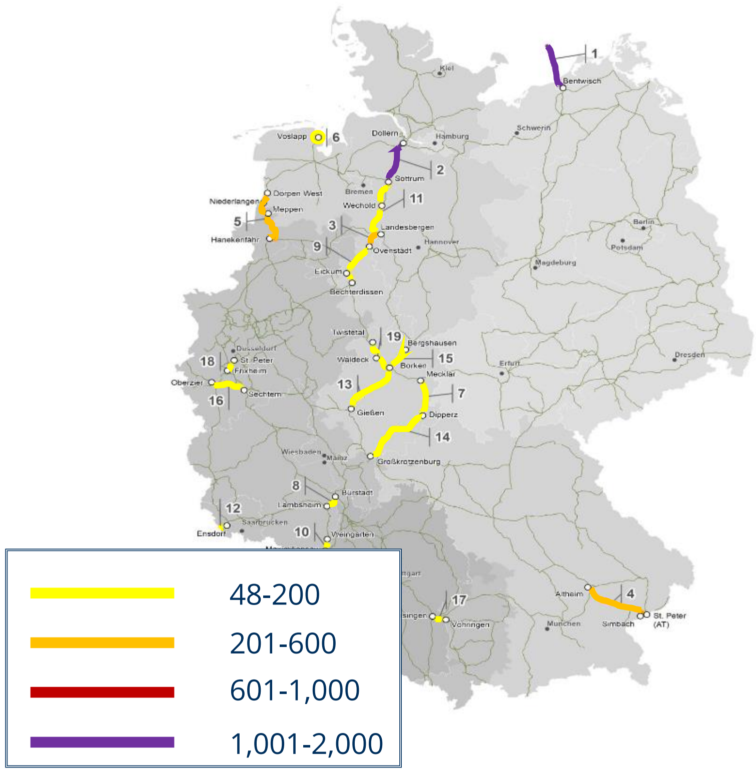
Agenda for today…

Increasing congestion management cost motivates research on alternative market design concepts

Total congestion management cost in Germany



# of line overload hours in Germany 2021



[Based on Bundesnetzagentur]

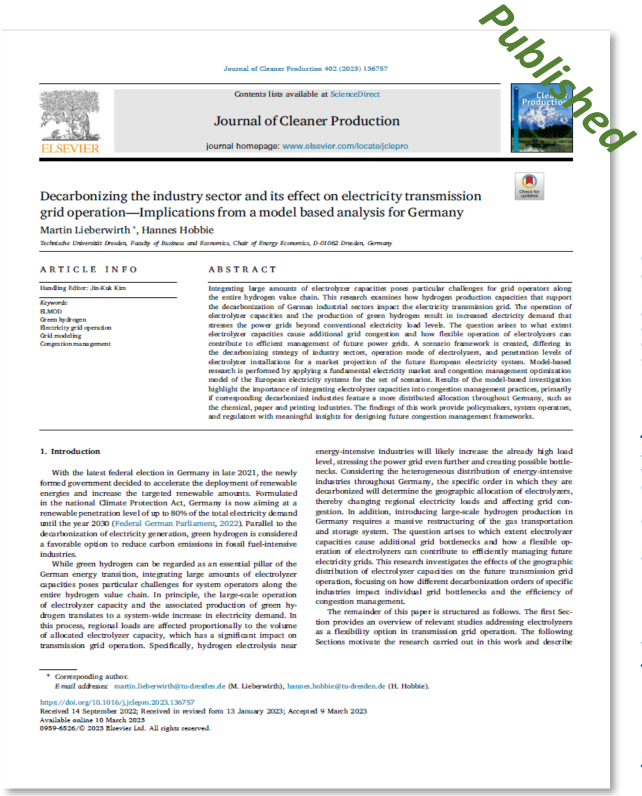
Green hydrogen production through electrolysis planned for Germany in 2030 imputes increased electricity demands

- Green hydrogen is considered a promising alternative for providing industries with low-carbon fuels
  - ➢ German legislation institutionalises electrolyser expansion up to **10 GW** until 2030
  - ➢ Production will need an additional electricity demand of approximately **28 TWh**
- Additional load created by electrolyser operation **poses challenges** for transmission grid operation
- However, electrolyser capacity being a **flexible demand side application** can provide also redispatch capacity to system operators
- **Evaluating the effects of domestic green hydrogen production on transmission grid operation seems necessary**

Industry decarbonisation poses particular challenges for transmission system operation

http://hdl.handle.net/10419/262112

Focus:
Where to install electrolyser? – near RES sites or near hydrogen demands



https://doi.org/10.1016/j.jclepro.2023.136757

Focus:
Which industries to be decarbonized by domestic hydrogen production?

Agenda for today…

ELTRAMOD determines the cost optimal power plant dispatch to serve the electricity demand

ELTRAMOD | **ELMOD**

Market Model
Optimisation of plant dispatch considering zonal market clearing

Grid- (Congestion Management) Model
Optimisation of congestion relief considering transmission constraints

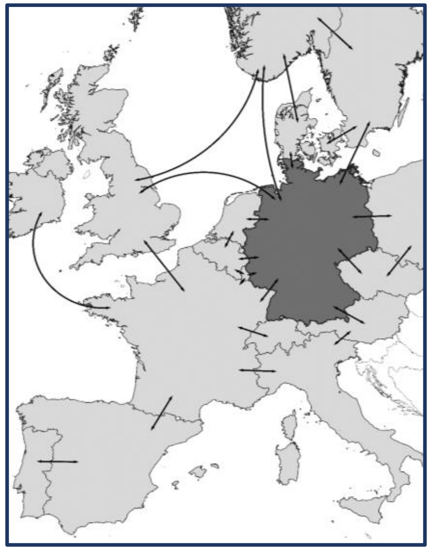
1h time resolution
- RES capacity factors
- Electricity demand
- Plant availability
- Fuel prices
- CO_2 prices
- NTC

Time series data

+

Static
- Plant capacity
- Technological characteristics
- Fixed costs
- NTC Projections

Fundamental data



$$min \sum_{p,t} G(p,t) * cost(p)$$

$$s.t. \sum_{p} G(p,t) - dem(t) = 0$$

$$G(p,t) \leq pmax(p) * avail(p,t)$$

Simplified illustration*

- Optimisation for 8760 hours of a year

- Wholesale power prices
- **Plant dispatch**
- CO_2 – Emissions

Model Output

* Number of equations and variables in the magnitude of millions…

ELMOD adjusts the market based power plant dispatch to correct for power flow restrictions

ELTRAMOD

Markt Modell
Optimisation of plant dispatch considering zonal market clearing

ELMOD

Grid- (Congestion Management) Model
Optimisation of congestion relief considering transmission constraints

Plant dispatch

1h time resolution

- Node-specific RES capacity factors
- Node-specific demand
- Fuel prices
- CO_2 prices

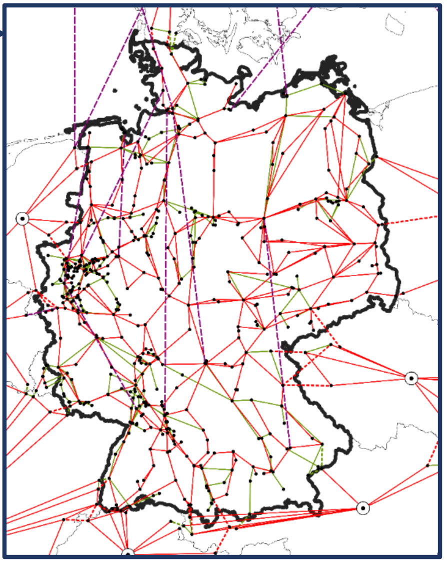
Time series data

+

Static

- Node-specific plant capacity
- Power line capacity
- Technological characteristcs

Fundamental data



$$\min \sum_{p,t} (RDup(p,t) - RDdown(p,t)) * cost(p)$$

$$s.t. \sum_{p} g\_da(p,t) + RDup(p,t) - RDdown(p,t) - dem(n,t) - NetI(n,t) = 0$$

$$f(NetI(n,t)) = LF(l,t)$$

$$g(LF(L,t)) \leq line\ capacity(l)$$

$$h(RDup(p,t), RDdown(p,t)) \leq z(p,t)$$

Simplified illustration*

- Rolling planning optimisation (e.g. 48 hours)

- Load flows (DC Approximation)
- **Redispatch**
- grid congestions
- **RES curtailment**

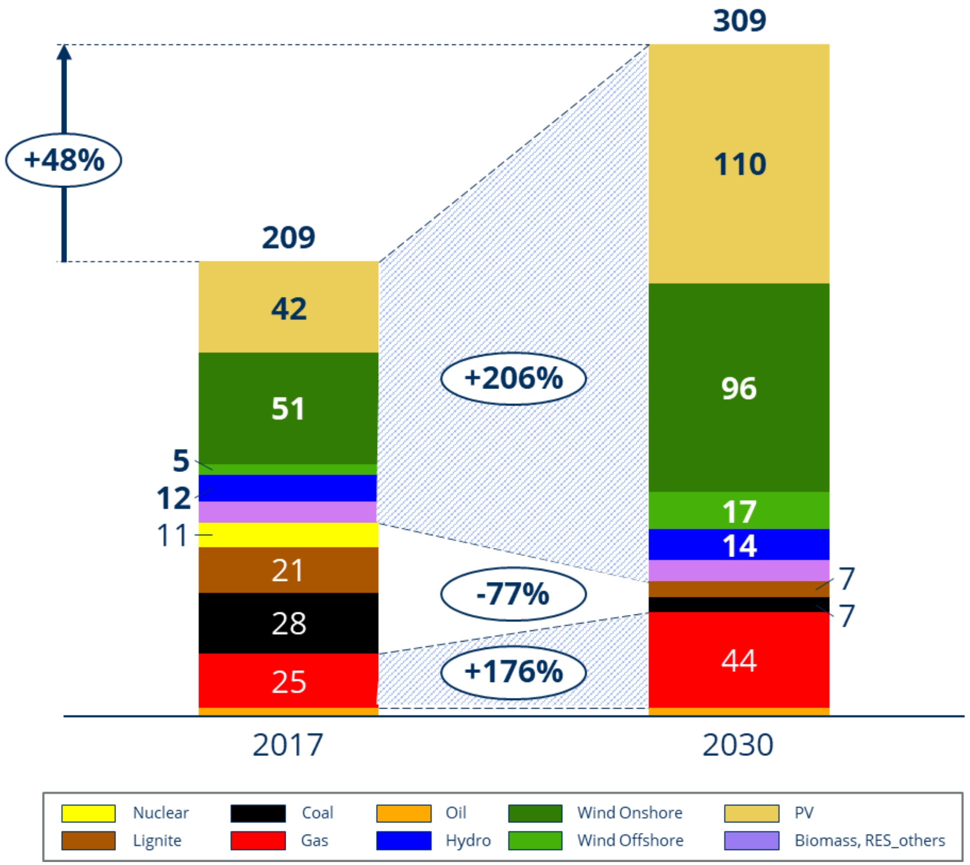
Model Output

* Number of equations and variables in the magnitude of hundreds of millions...

Agenda for today…

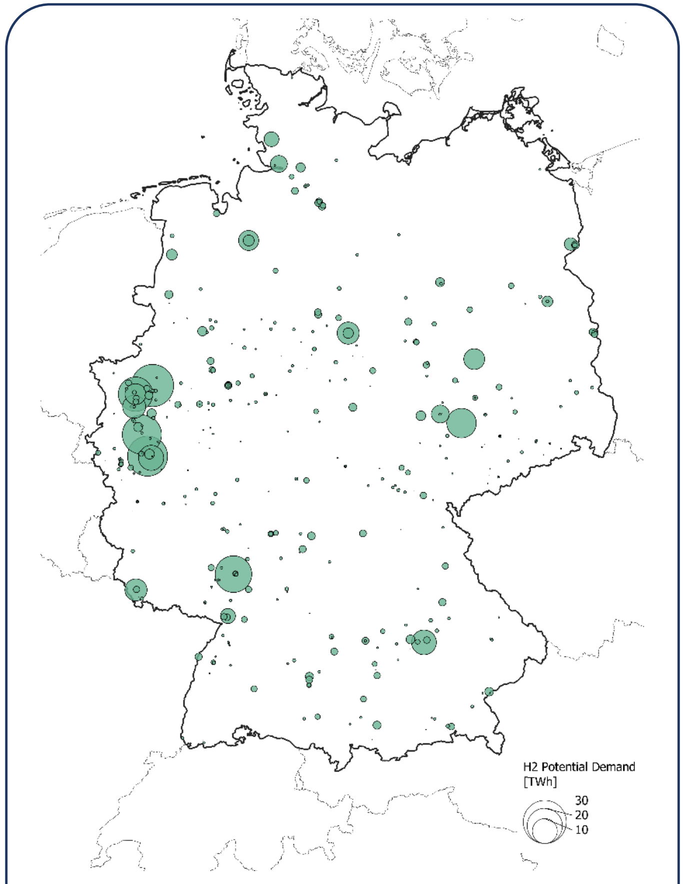
Power market model is parametrised with 2030 target year data based on TYNDP 2020

Assumed installed German generation capacity [GW]



- RES Capacities almost doubled
- No Nuclear power, highly reduced Lignite and coal capacities
- Additional gas-fired power plant capacities are spatially assigned to nodes where coal, lignite and nuclear power is phased out to compensate for the loss of flexible generation capacities
- Fuel prices, CO_2 prices, NTC's and the generation capacities of other countries are taken from ENTSOE TYNDP 2020 scenario „*Distributed Energy*"
- Transmission Grid expansion is taken from NEP2030 and TYNDP2020

Scenario framework reflects 2030 estimated industry hydrogen demands



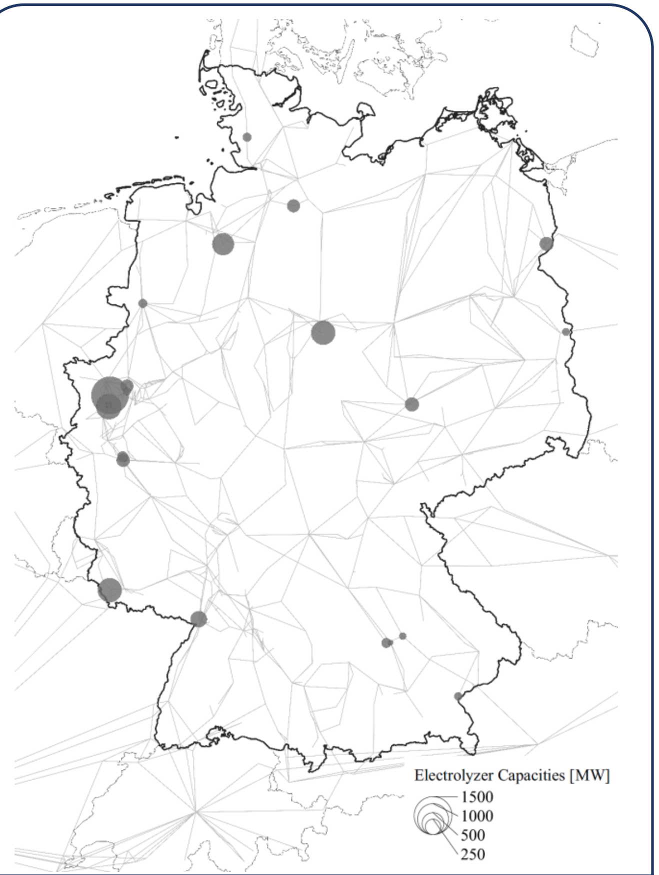
H_2 Potential Demand

- The order in which industry sectors are being decarbonized with domestic H2 affects the regional distribution of electrolyser capacity
- H_2 demands are based on Neuwirth et al. (2022)*

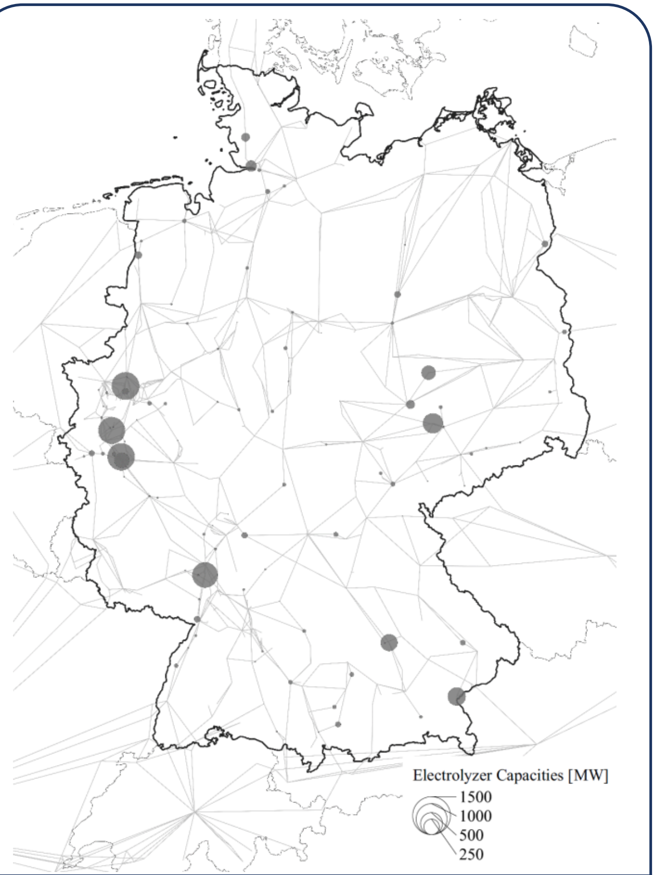
Industry Sector	Potential H_2 Demand [TWh]	No. of Sites	TRL	Regional Distribution
Refineries	22.6	16	8-9	Central
Chemical Industry	161.0	30	8-9	Decentral
Paper and Printing	30.5	162	8-9	Decentral
Non-metallic Minerals	8.3	46	4-5	Decentral
Mineral Processing	30.7	84	4-5	Decentral
Metal Processing	18.0	30	4-5	Decentral
Non-ferrous metals	3.7	4	4-5	Central
Steel, primary	52.2	8	7-8	Central

* Neuwirth, M., Fleiter, T., Manz, P., Hofmann, R., 2022. The future potential hydrogen demand in energy-intensive industries - a site-specific approach applied to germany. Energy Conversion and Management 252. doi:10.1016/j.enconman.2021.115052.

Spatial distribution of electrolyzer capacities forms additional input for the grid model



Central distribution of EL capacities

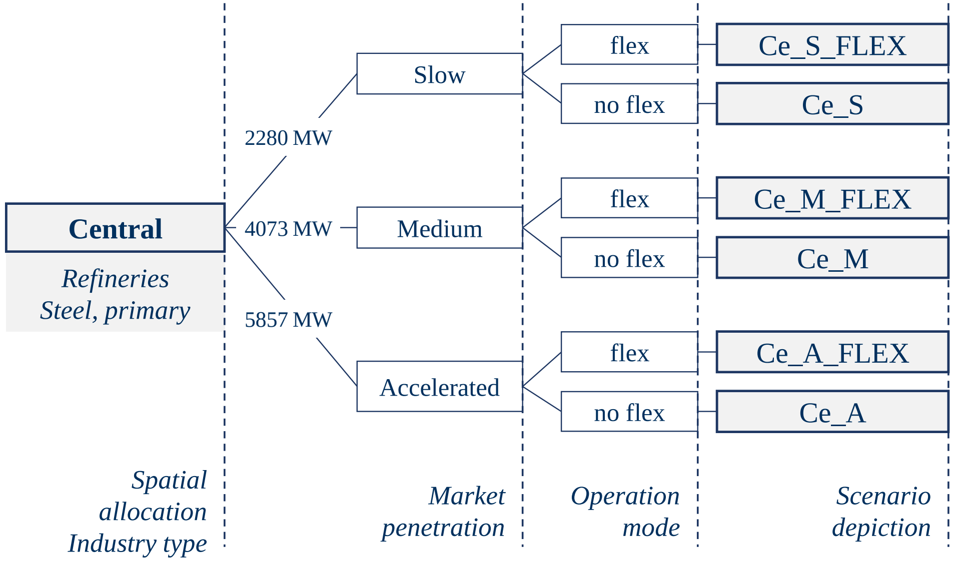


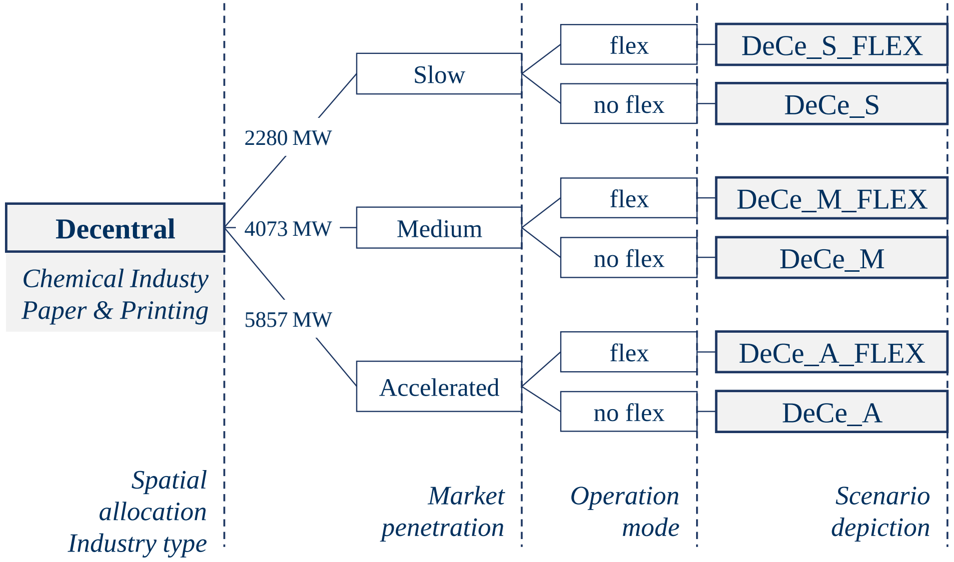
Decentral distribution of EL capacities

- Assignment of electrolyzer capacities to grid nodes is essential to determine effects on congestion management
- Centralized distribution (24 sites) concentrates electrolyzer capacities in Western and Northern Germany
- Decentralized distribution (192 sites) of electrolyzer capacities is more widespread with centres in West, East and South Germany
- Sensitivity of electrolyzer impact is reflected through different capacity volumes

12 scenarios differing in the geographical distribution and operation mode of electrolyser capacity created

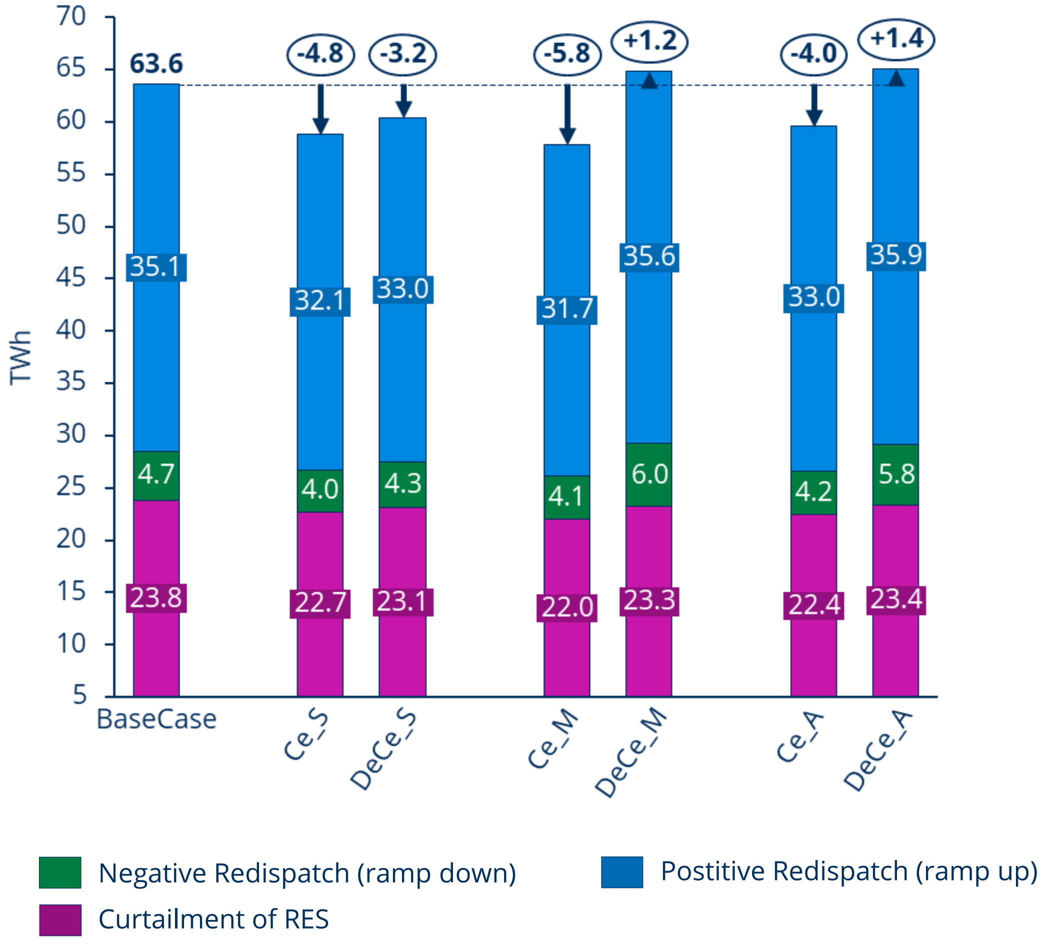
1. We distinguish between *centralized* and *decentralized* spatial allocation
2. We assume a *slow*, *medium* and *accelerated* market penetration of electrolyser capacity
3. We consider two different modes of electrolyser operation – flexible and non-flexible





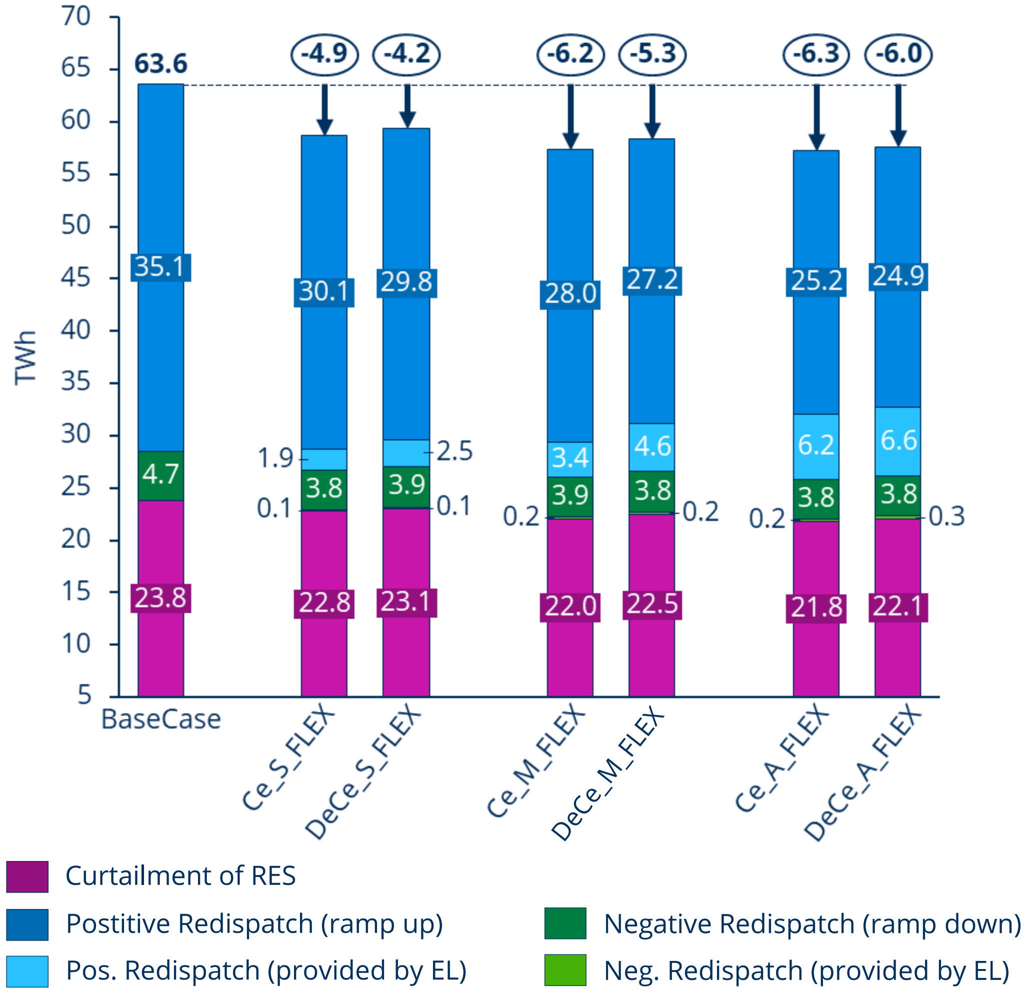
Agenda for today…

Aggregated Results (no_flex): Electrolyser distribution in the central scenario causes no additional increase in congestion management volumes



- Congestion management volume increases in a decentralised distribution (chemical industry, paper & printing) with increasing market penetration levels
- Congestion management volumes stay below the base case volumes in the central scenarios (chemical industry, primary steel)
- Reduced curtailment volumes can be observed in every centralised deployment scenario

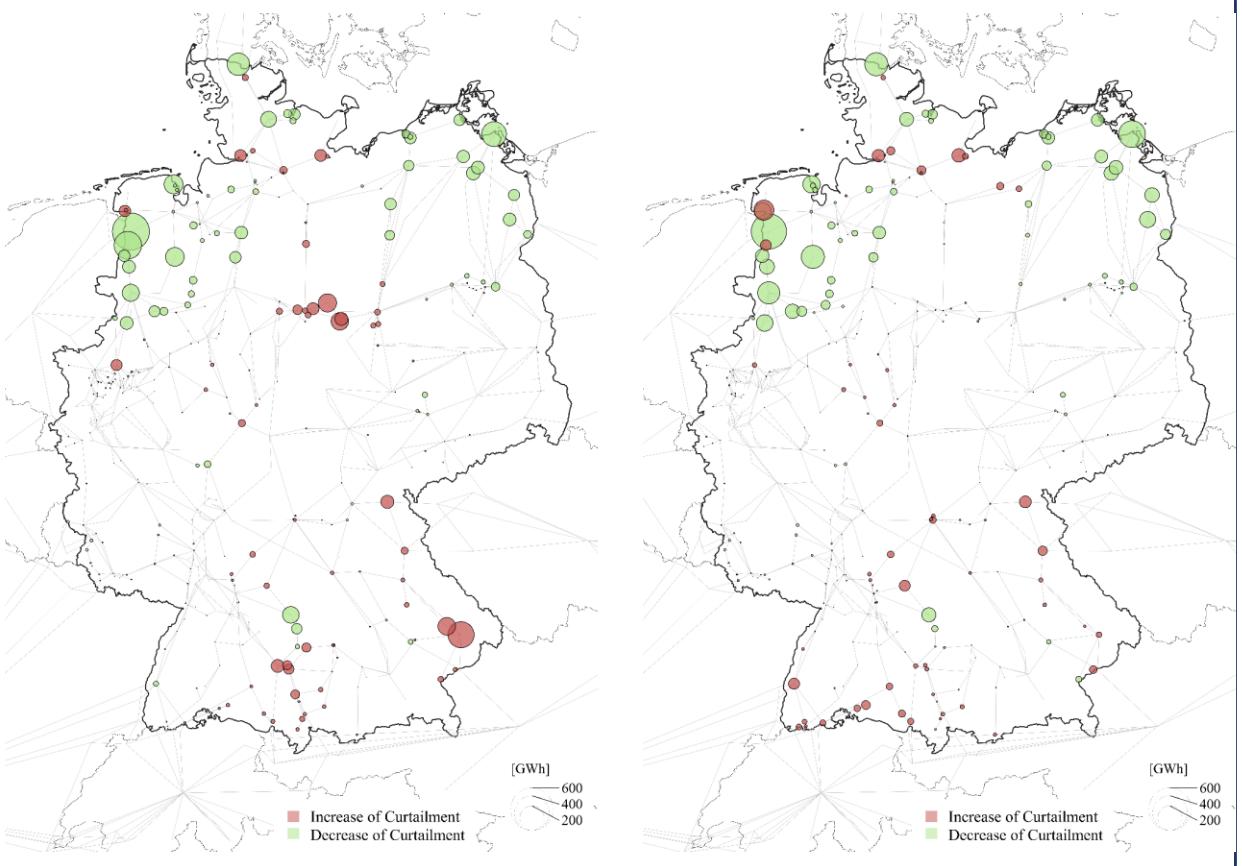
Aggregated Results (flex): Electrolyser capacity contributes significantly to grid relief by providing flexible load shifting quantities



- Congestion management volume decreases proportional to the market penetration of electrolyser capacities
- Difference between the scenarios regarding their spatial distribution (central vs. decentral) varies only by a small margin
- Electrolyser redispatch increasingly replaces redispatch from conventional power generators
- Reduced curtailment volume can now be observed in every scenario

<u>Regional Results (*centralized*):</u> Flexible operation of electrolysers mitigate the increase in curtailment volumes

Increase/decrase of **Curtailment** in the **centralized** Scenarios

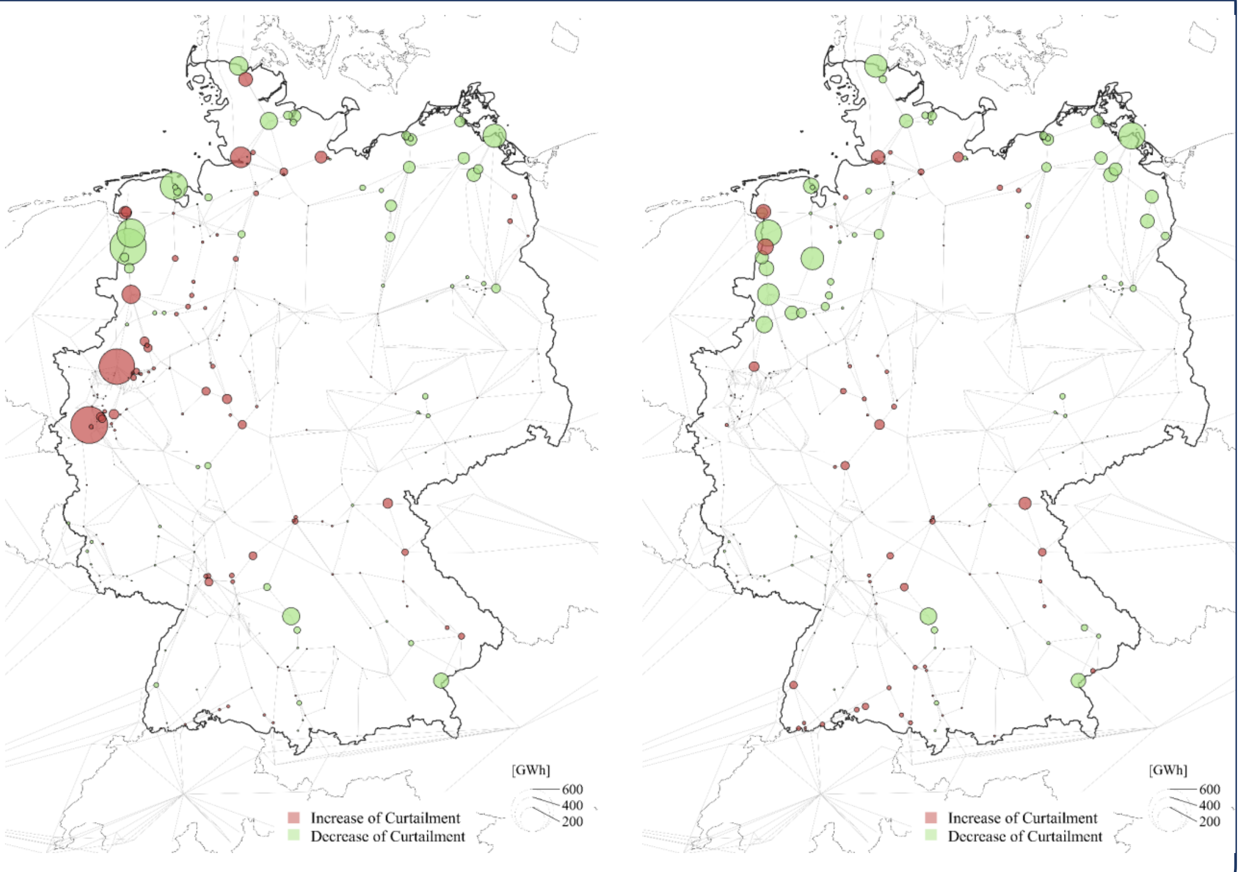


No flexibility of electrolysers | **Flexibility** of electrolysers

- Distribution of electrolyser capacities coincides with regions of large curtailment
- Electrolyser operation decreases curtailment volumes especially in North-West Germany considering both modes of operation
- Increase of curtailment in Central and South Germany in a scenario with no flexibility of electrolyser
  - Additional load from electrolysers exerts stress on transmission grid lines in certain regions
  - Effect can be counterbalanced if electrolysers are dispatched for congestion management

<u>Regional Results (*decentralized*):</u> Electrolyzer distribution in the decentral scenario risks integration of RES feed-in along critical corridors

Increase/decrase of **Curtailment** in the **decentralized** Scenarios



No flexibility of electrolyzers | With flexibility of electrolyzers

- Distribution of electrolyzer share a great proximity with electricity load centres in West and South Germany
- Curtailment increase significantly at two nodes in West Germany
- Electrolyzer operation in the decentral scenario creates additional bottlenecks at the north-to-south corridor
  - ➢ Integrating large volumes of RES feed-in is compromised
- Bottlenecks can be avoided if a flexible operation is assumed

Summary: Hydrogen production nearby refineries and steel production can positively contribute to RES integration independently from operation mode

- Renewable energy integration can **benefit** from electrolyser operation depending on the geographic distribution:
  - ➢ Total congestion volumes can be reduced if electrolyser capacities are installed near **refineries** and **steel production facilities** regardless the operation mode
  - ➢ Operation of electrolyser capacities at **chemical industry** and **paper & printing** facilities additionally stresses transmission grid lines

Conclusion: Electrolyser capacity should be considered in the design of future congestion management frameworks

- **Regulatory framework** on flexibility provision from electrolyser capacity required, especially for decarbonisation of ‘centralised’ industries

- Regulation must enable electrolyser owners to **participate** in congestion management practises

- Future research should investigate potential design options for congestion management frameworks and **incentive mechanisms** for flexible demand side applications

Thank you for your attention

Martin Lieberwirth

Tel.: +49 (0) 351/463-39766
Email: martin.lieberwirth@tu-dresden.de
Web: ee2.biz

Hannes Hobbie

Tel.: +49 (0) 351/463-39894
Email: hannes.hobbie@tu-dresden.de
Web: ee2.biz

Chair of Energy Economics
Technische Universität Dresden
Münchner Platz 3
01069 Dresden