


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

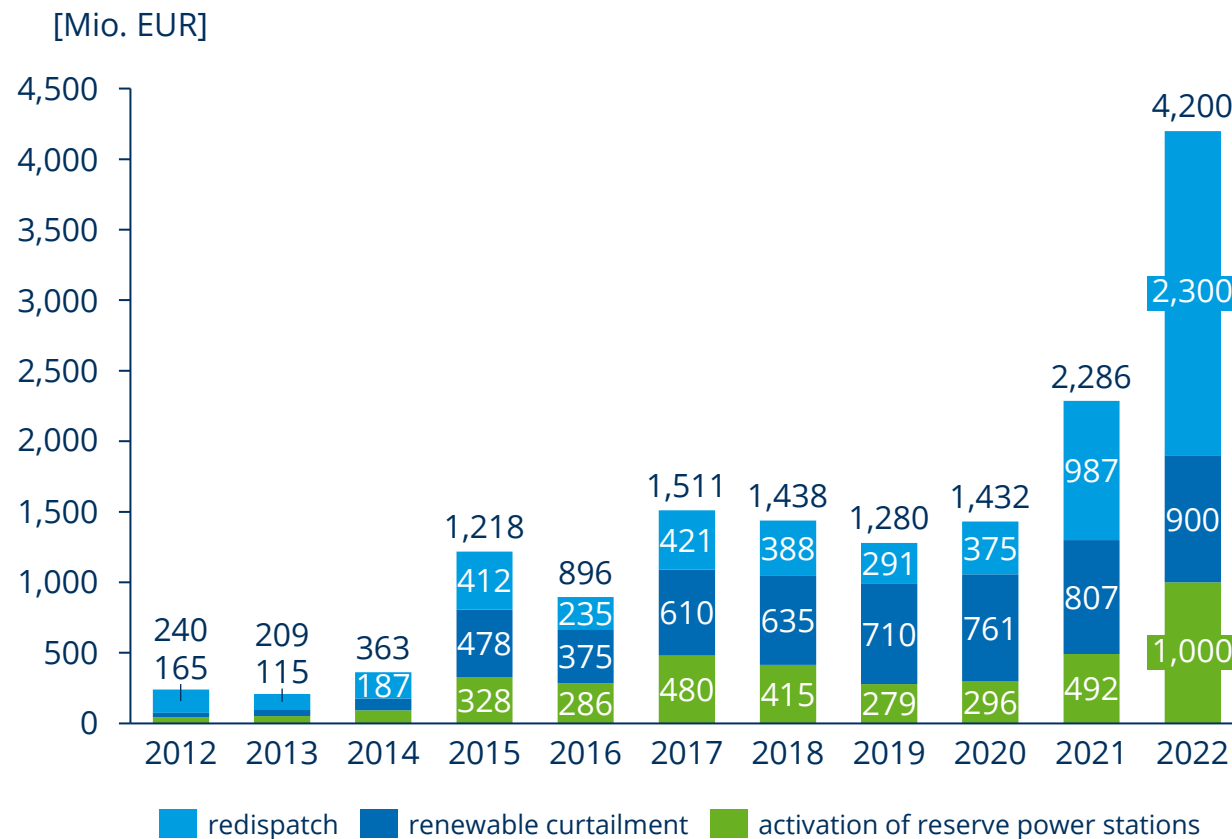
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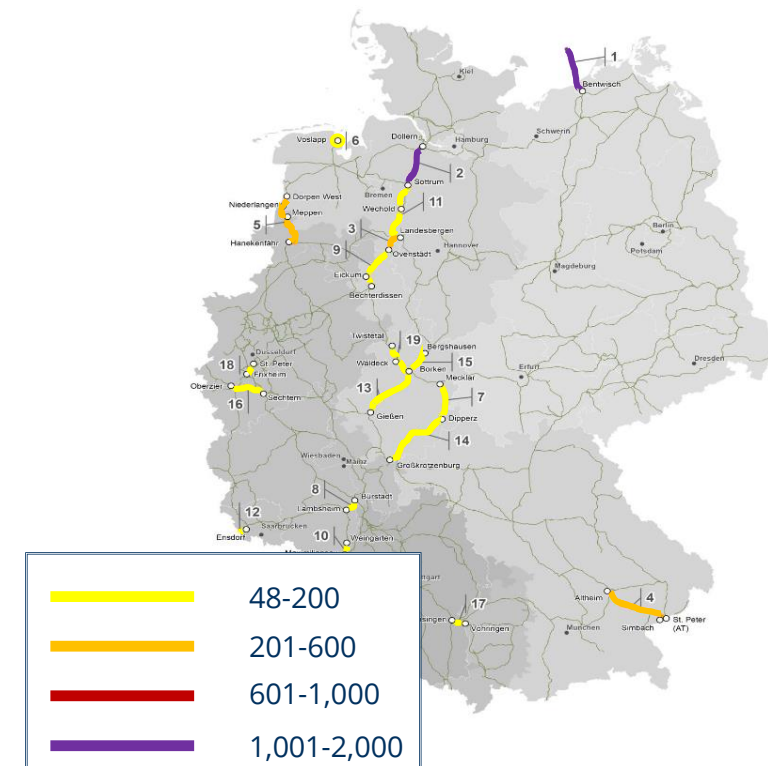
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Increasing congestion management cost motivates research on alternative market design concepts

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

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Compounding or Curative? Investigating the impact of electrolyzer deployment on congestion management in the German power grid
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ARTICLE INFO
Keywords: Hydrogen, Green hydrogen, Electricity grid operation, Congestion management

ABSTRACT
Integrating large amounts of hydrogen production capacities for decarbonizing energy intensive industries in Germany can be challenging for transmission system operators. This research investigates interactions of hydrogen production deployment pathways and associated congestion management policies with the operation of the German electricity transmission system for future market projections. Hydrogen electrolysis imposes additional electricity loads above conventional levels. A scenario framework is created representing different geographic electrolyzer deployment pathways and congestion management regulations for electrolyzer operation. Financial electricity market modeling and load flow optimization are proposed to evaluate resulting congestion management volumes to resolve grid bottlenecks associated with the market clearing dispatch. Overall results of this work highlight the importance of designing congestion management frameworks that enable efficient utilization of electrolyzers as a redispatch capacity, primarily if a demand-oriented deployment of electrolyzer installations near energy-intensive industries is assumed to support renewable energy integration. Differences in congestion management cost between demand- and supply-oriented deployment pathways of electrolyzer capacity lie in the range of 0.77-0.92 €/MWh for electrolyzers versus 0.10-0.23 €/MWh for electrolyzers as a redispatch capacity. The findings of this work assist policymakers and regulators with valuable insights into design options for future congestion management frameworks.

1. Introduction
The German energy landscape has seen a massive restructuring fostering ambitious national decarbonization targets toward reaching climate neutrality in the gas. A significant roll-out of renewable energy installations in the electricity sector could be observed since the introduction of the renewable support legislation, dating back to early 1990. Current German energy policies emphasize several activities to reduce carbon emissions in energy-intensive industry sectors. Green hydrogen production is a central pillar for decarbonizing fossil fuel-intensive industry sectors in this context. While the transformation toward hydrogen-based production processes is considered a promising decarbonization strategy, integrating large amounts of hydrogen electrolyzers into the German energy system poses particular challenges for system operators. Electrolyzer operation creates additional electricity loads beyond the conventional electricity demands, stressing transmission power lines. The question arises as to which extent electrolyzer installations cause additional grid bottlenecks and how improved congestion management regulation promotes a flexible operation of electrolyzer capacities, contributing to managing future transmission grids for integrating increasing amounts of renewable energy generation. The geographic distribution of future electrolyzer installations in Germany is naturally uncertain. Operating electrolyzers directly connected with renewable electricity generation units, e.g., wind and solar farms, might reduce hydrogen generation costs, incentivizing electrolyzer investments at locations with large renewable generation capacities installed. Moreover, recognizable amounts of renewable installations will soon reach the end of the period they are granted a fixed feed-in premium, thus falling out of the German renewable support legislation. Producing green hydrogen through deploying power to gas technologies in conjunction with power purchase agreements to ensure produced hydrogen quantities provides renewable operators with additional business opportunities. On the contrary, energy-intensive industries are increasingly challenged with the task of decarbonizing production processes and likely require hydrogen supply at the production facility. Nevertheless, hydrogen transportation infrastructures are yet to be developed, stimulating investments into electrolyzers near

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

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Decarbonizing the industry sector and its effect on electricity transmission grid operation—Implications from a model based analysis for Germany
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ARTICLE INFO
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Keywords: ELMOD, Green hydrogen, Electricity grid operation, Grid modeling, Congestion management

ABSTRACT
Integrating large amounts of electrolyzer capacities pose particular challenges for grid operators along the entire hydrogen value chain. This research examines how hydrogen production capacities that support the decarbonization of German industrial sectors impact the electricity transmission grid. The operation of electrolyzer capacities and the production of green hydrogen result in increased electricity demand that stress the power grids beyond conventional electricity load levels. The question arises to what extent electrolyzer capacities cause additional grid congestion and how flexible operation of electrolyzers can contribute to efficient management of future power grids. A scenario framework is created, differing in the decarbonizing strategy of industry sectors, operation mode of electrolyzers, and penetration levels of electrolyzer installations for a market projection of the future European electricity system. Model-based research is performed by applying a fundamental electricity market and congestion management optimization model of the European electricity systems for the set of scenarios. Results of the model-based investigation highlight the importance of integrating electrolyzer capacities into congestion management practices, primarily if corresponding decarbonized industries feature a more distributed allocation throughout Germany, such as the chemical, paper and printing industries. The findings of this work provide policymakers, system operators, and regulators with meaningful insights for designing future congestion management frameworks.

1. Introduction
With the latest federal election in Germany in late 2021, the newly formed government decided to accelerate the deployment of renewable energies and increase the targeted renewable amounts. Formulated in the national Climate Protection Act, Germany is now aiming at a renewable penetration level of up to 60% of the total electricity demand until the year 2030 (Federal German Parliament, 2022). Parallel to the decarbonization of electricity generation, green hydrogen is considered a favorable option to reduce carbon emissions in fossil fuel-intensive industries. While green hydrogen can be regarded as an essential pillar of the German energy transition, integrating large amounts of electrolyzer capacities poses particular challenges for system operators along the entire hydrogen value chain. In principle, the large-scale operation of electrolyzer capacity and the associated production of green hydrogen translates to a system-wide increase in electricity demand. In this process, regional loads are affected proportionally to the volume of allocated electrolyzer capacity, which has a significant impact on transmission grid operation. Specifically, hydrogen electrolysis near energy-intensive industries will likely increase the already high load level, stressing the power grid even further and creating possible bottlenecks. Considering the heterogeneous distribution of energy-intensive industries throughout Germany, the specific order in which they are decarbonized will determine the geographic allocation of electrolyzers, thereby changing regional electricity loads and affecting grid congestion. In addition, introducing large-scale hydrogen production in Germany requires a massive restructuring of the gas transportation and storage system. The question arises to which extent electrolyzer capacities cause additional grid bottlenecks and how a flexible operation of electrolyzers can contribute to efficiently managing future electricity grids. This research investigates the effects of the geographic distribution of electrolyzer capacities on the future transmission grid operation, focusing on how different decarbonization orders of specific industries impact individual grid bottlenecks and the efficiency of congestion management. The remainder of this paper is structured as follows. The first section provides an overview of relevant studies addressing electrolyzers as a flexibility option in transmission grid operation. The following sections motivate the research carried out in this work and describe

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

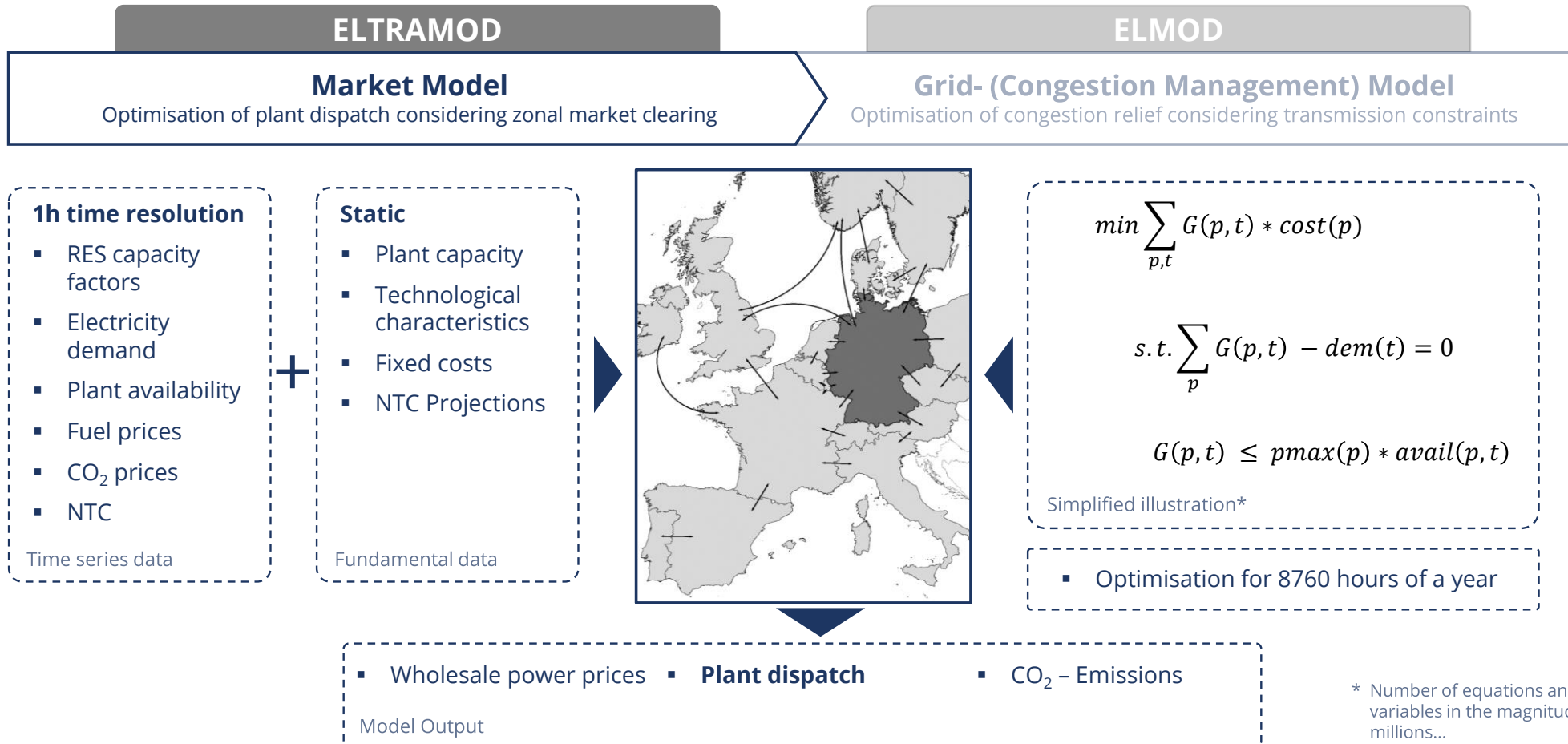
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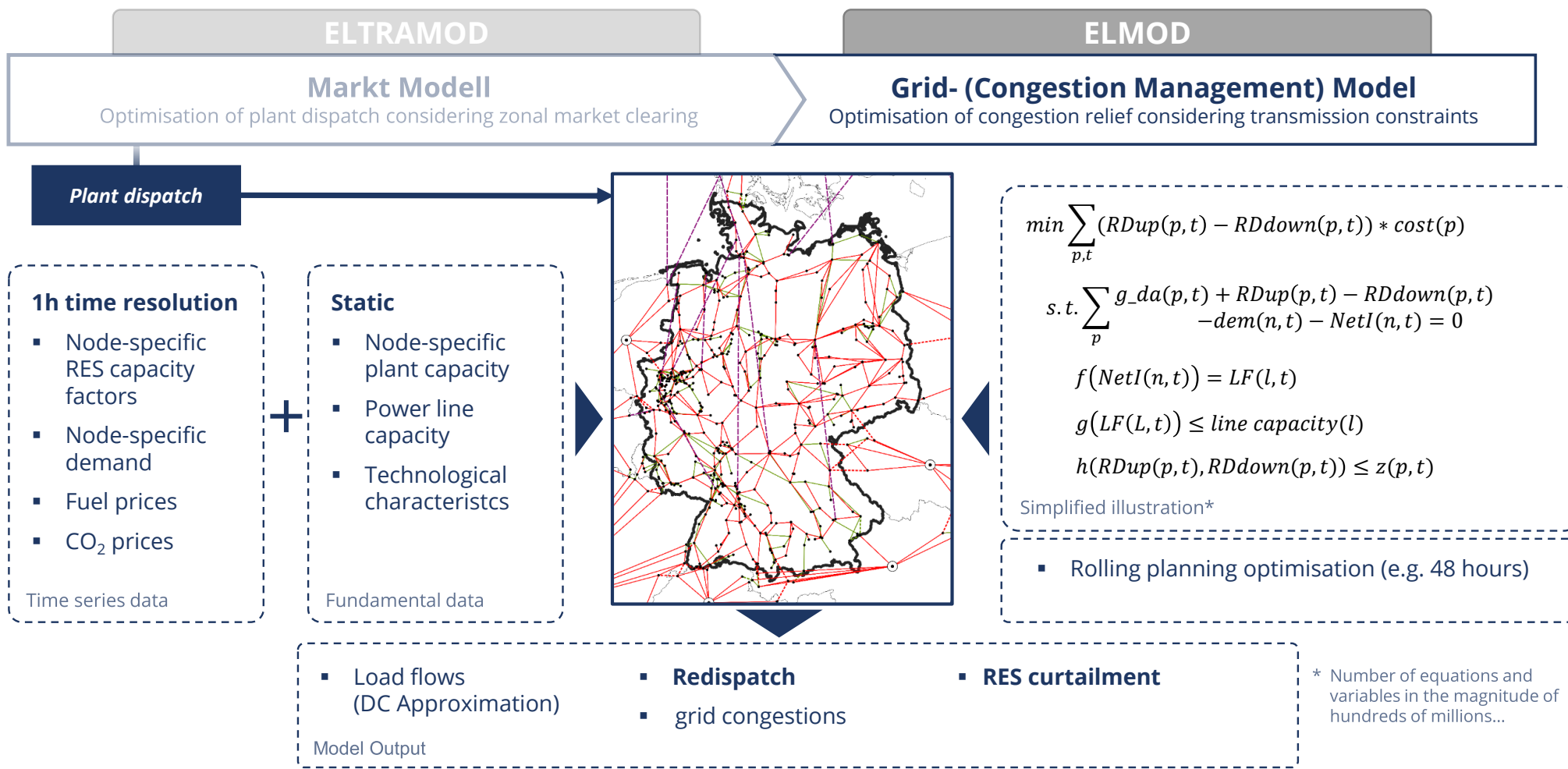


ELTRAMOD determines the cost optimal power plant dispatch to serve the electricity demand



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

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

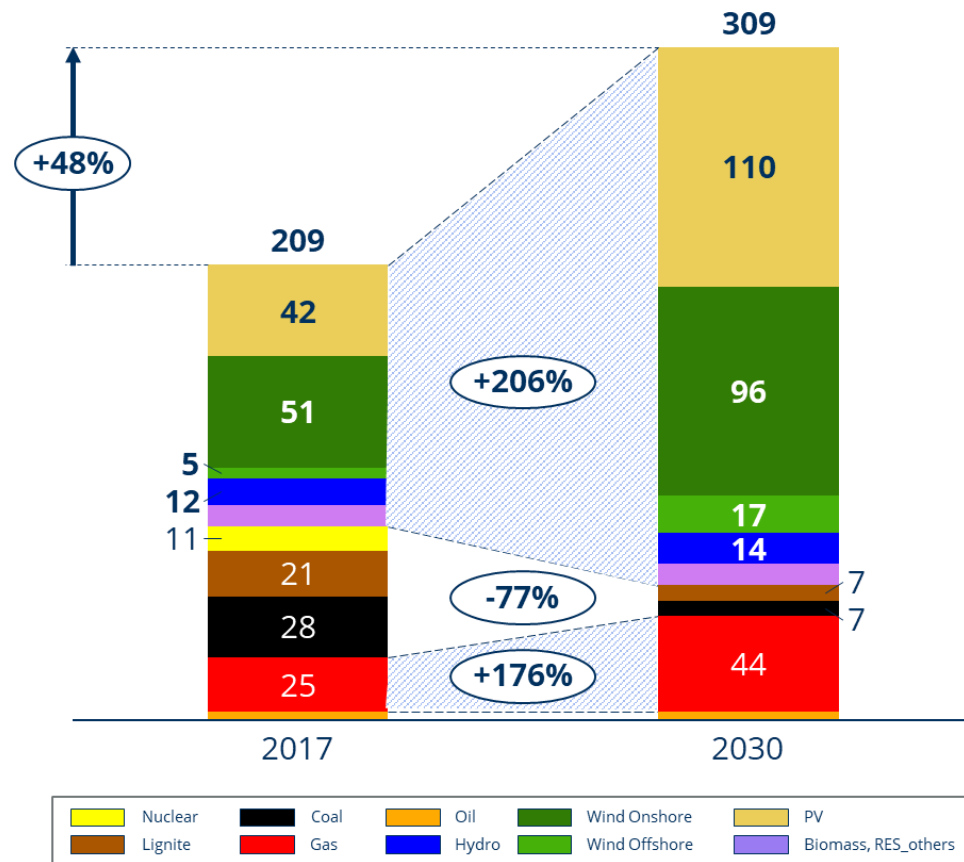


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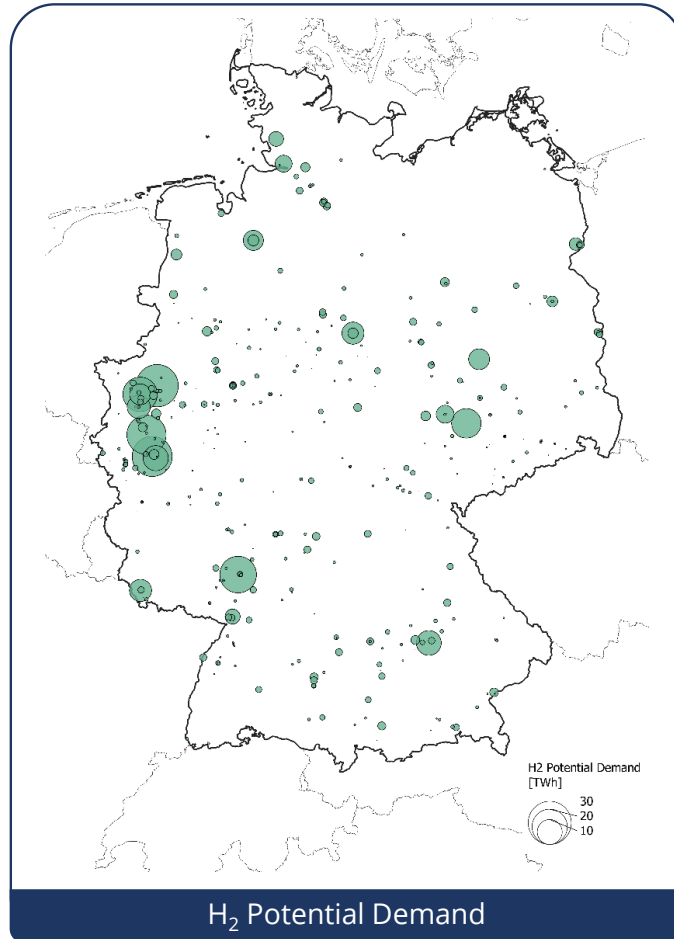
Power market model is parametrised with 2030 target year data based on TYNDP 2020

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, CO₂ 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

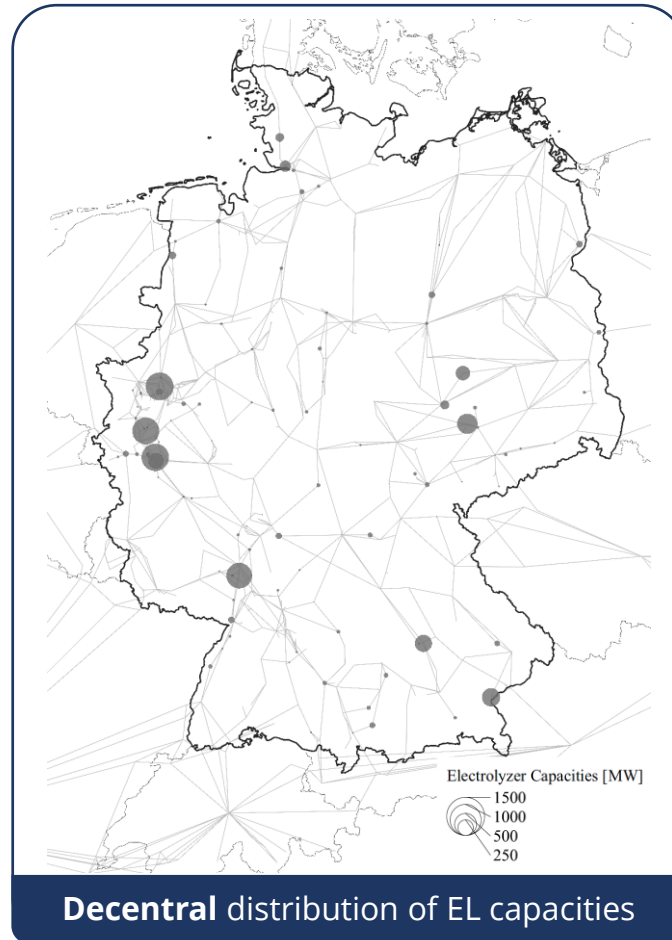
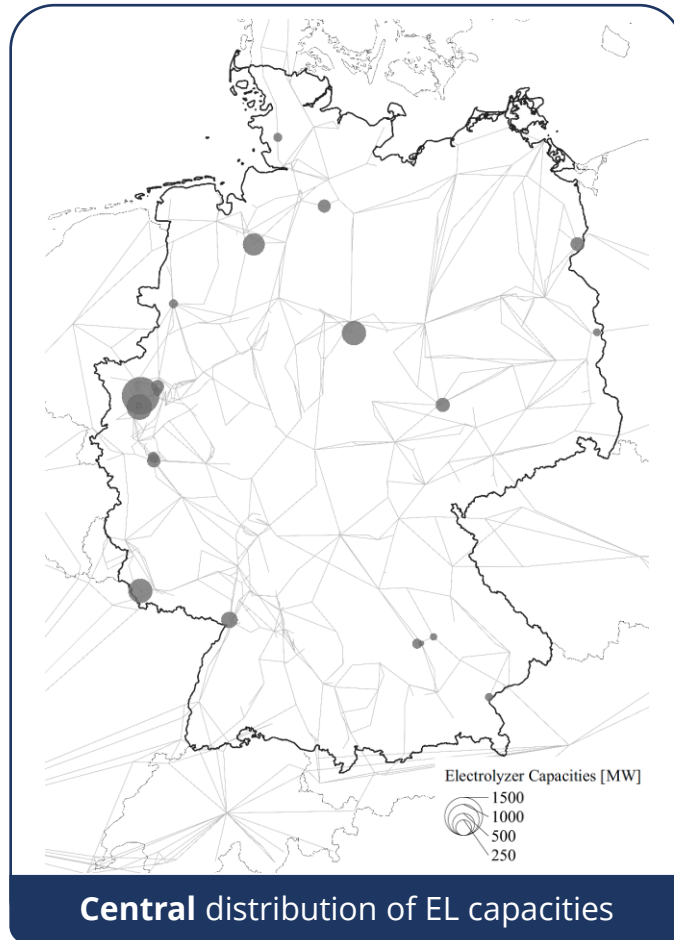


- The order in which industry sectors are being decarbonized with domestic H₂ affects the regional distribution of electrolyser capacity
- H₂ demands are based on Neuwirth et al. (2022)*

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.

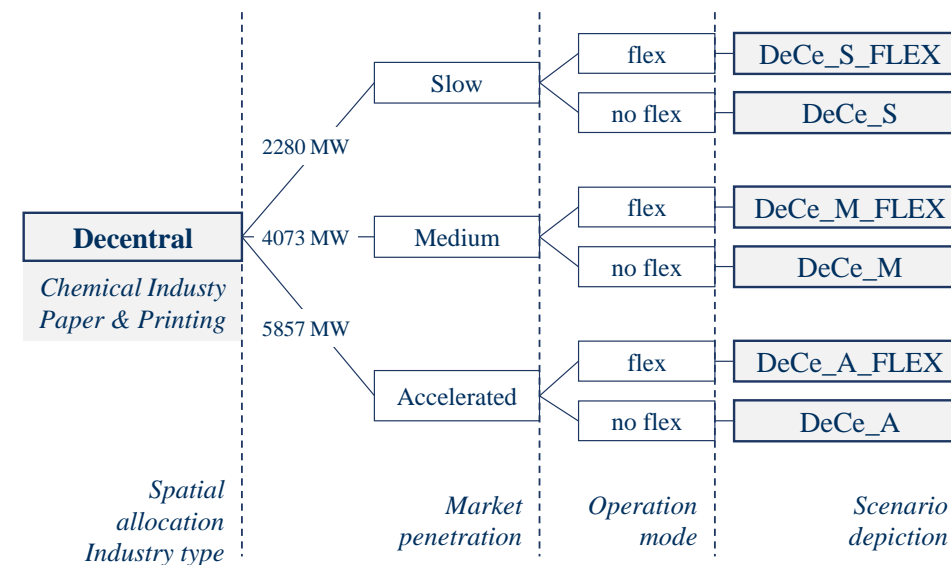
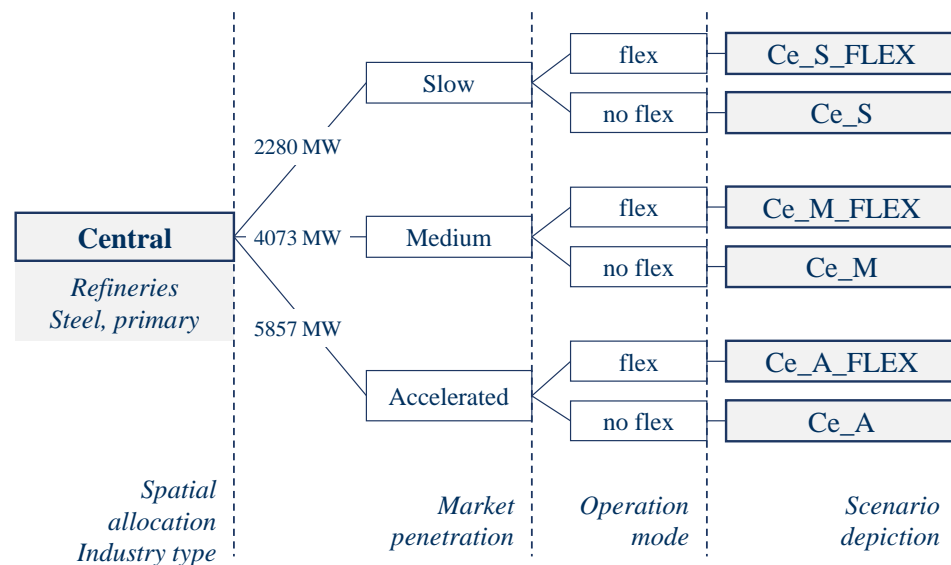
Spatial distribution of electrolyzer capacities forms additional input for the grid model




- 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

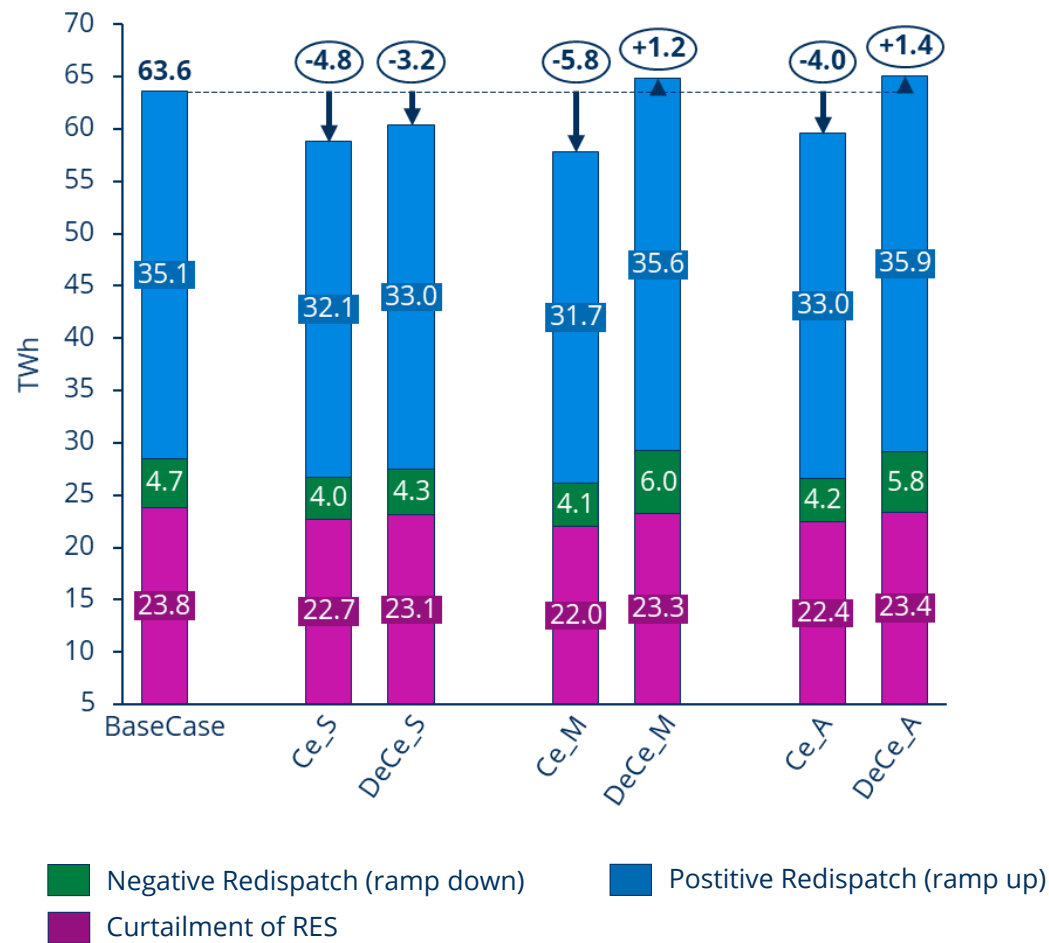
1. We distinguish between *centralized* and *decentralized* spatial allocation
2. We assume a *slow*, *medium* and *accelerated* market penetration of electrolyser capacity
3. We consider two different modes of electrolyser operation – flexible and non-flexible



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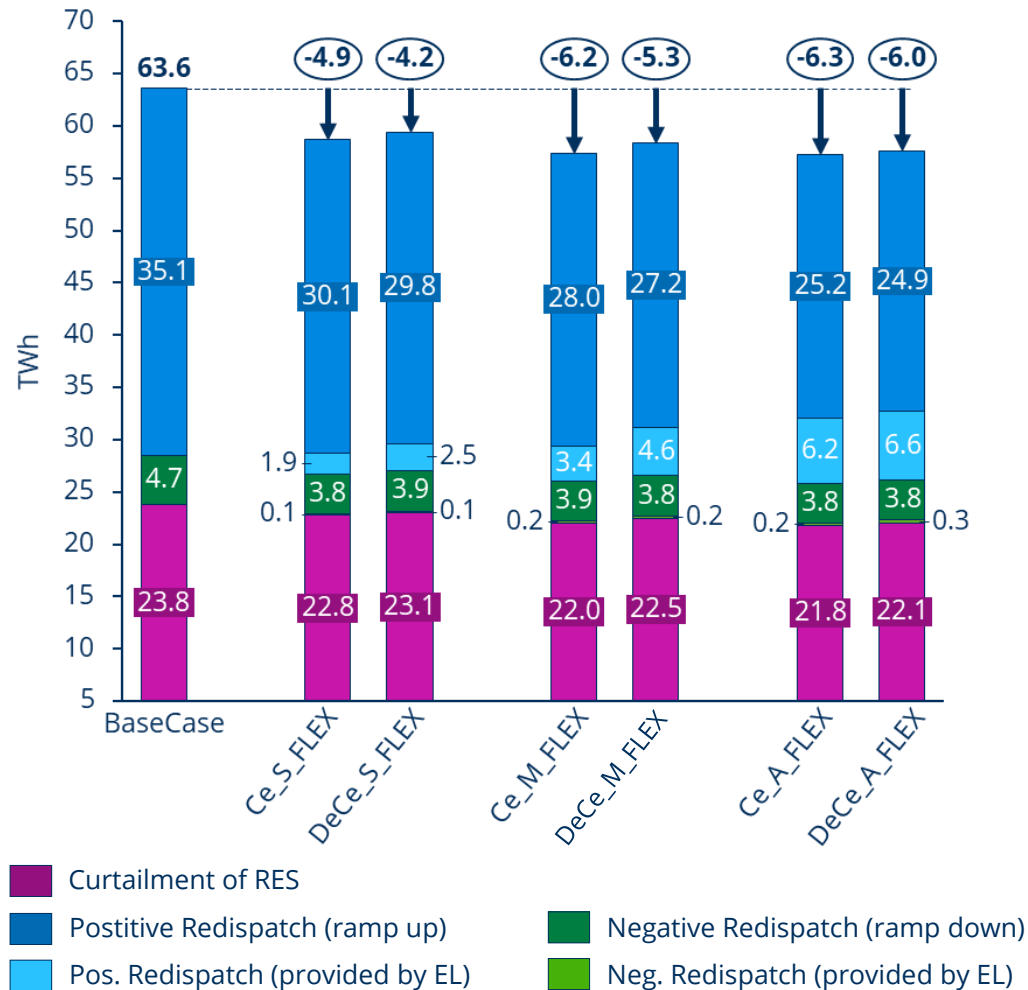
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Aggregated Results (no flex): Electrolyser distribution in the central scenario causes no additional increase in congestion management volumes



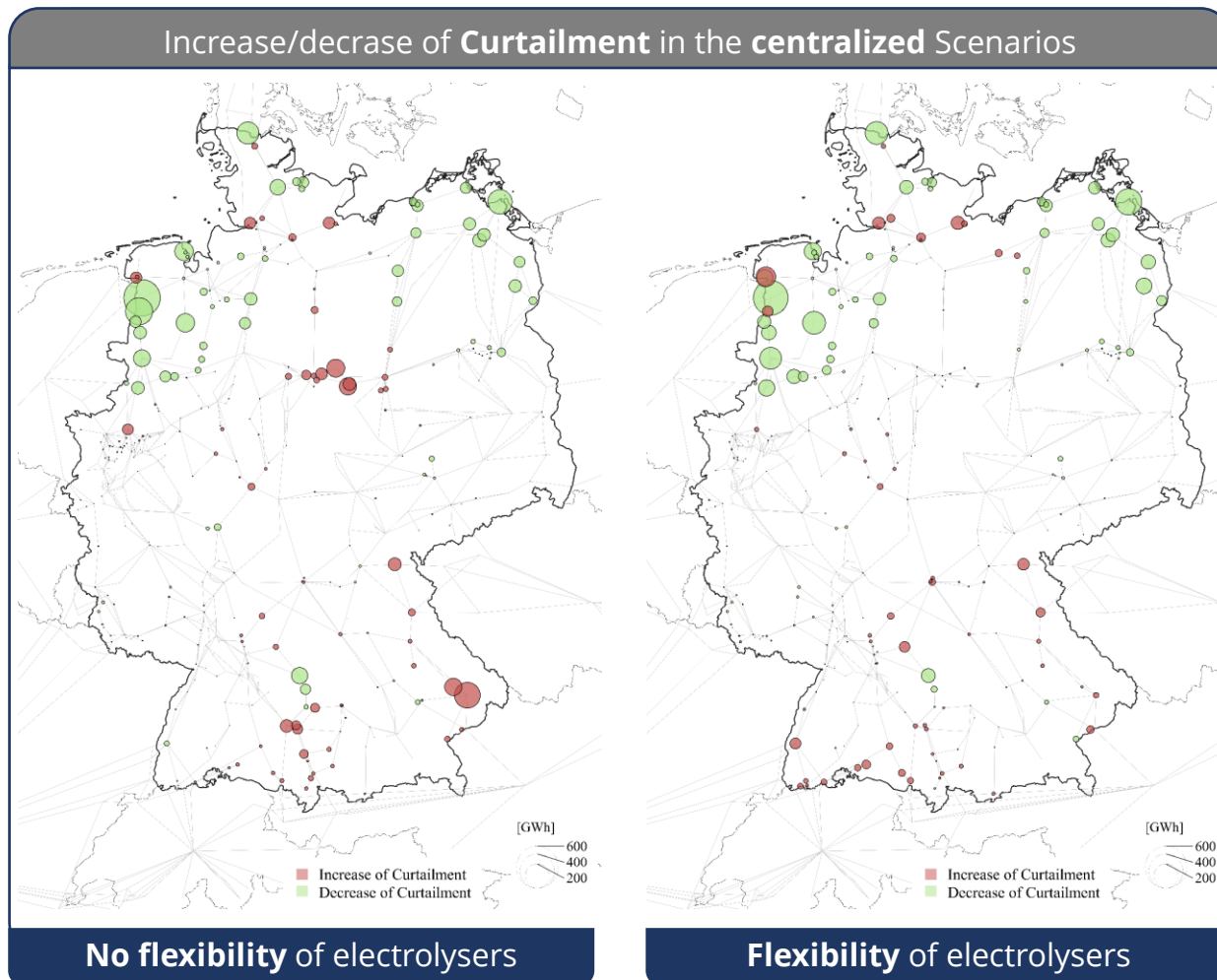
- Congestion management volume increases in a decentralised distribution (chemical industry, paper & printing) with increasing market penetration levels
- Congestion management volumes stay below the base case volumes in the central scenarios (chemical industry, primary steel)
- Reduced curtailment volumes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

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



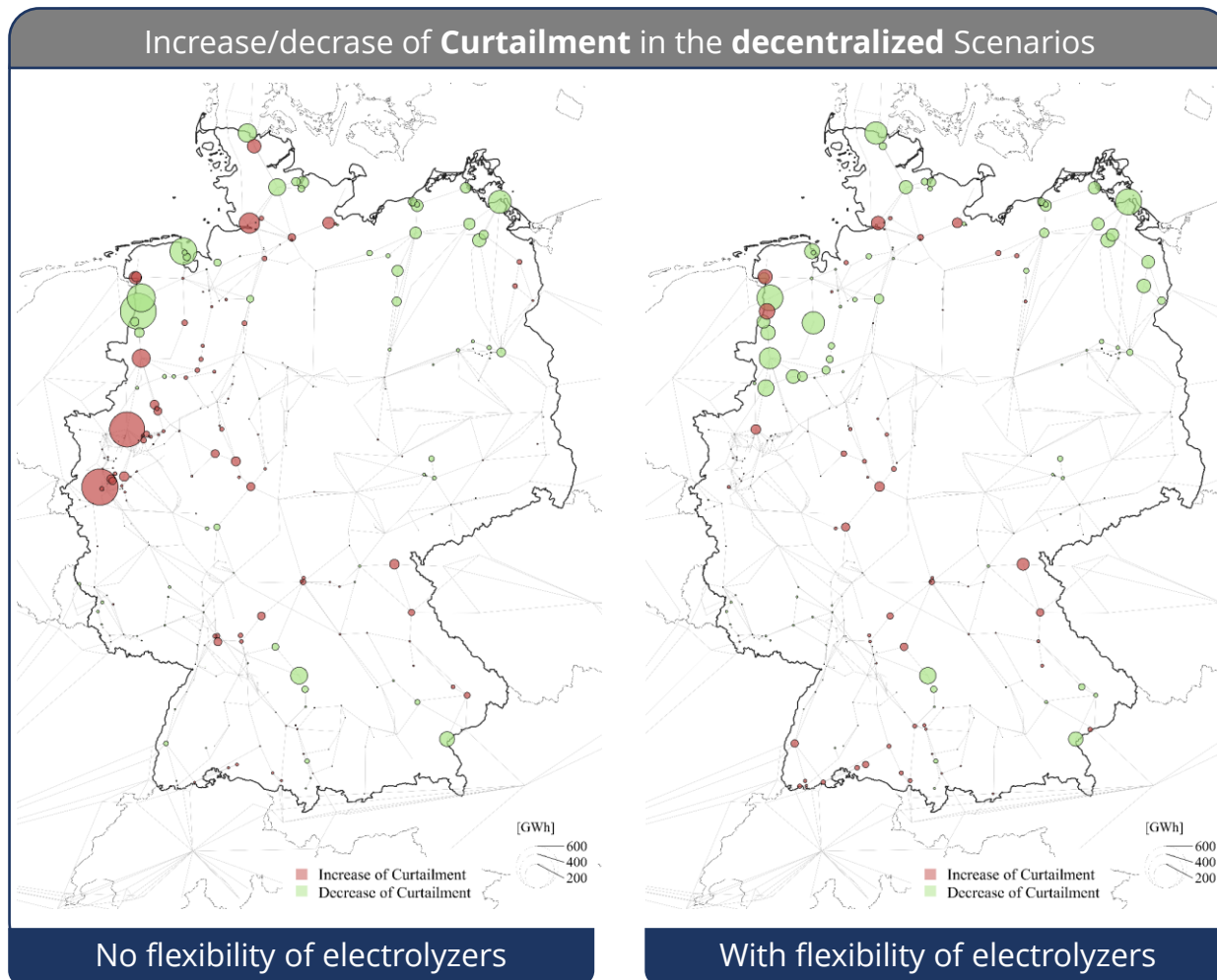
- Congestion management volume decreases proportional to the market penetration of electrolyser capacities
- Difference between the scenarios regarding their spatial distribution (central vs. decentral) varies only by a small margin
- Electrolyser redispatch increasingly replaces redispatch from conventional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

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



- 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

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



- 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

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