Spatial Incentives for Power-to-hydrogen through Market Splitting

Marco Sebastian Breder, Felix Meurer, Michael Bucksteeg, Christoph Weber

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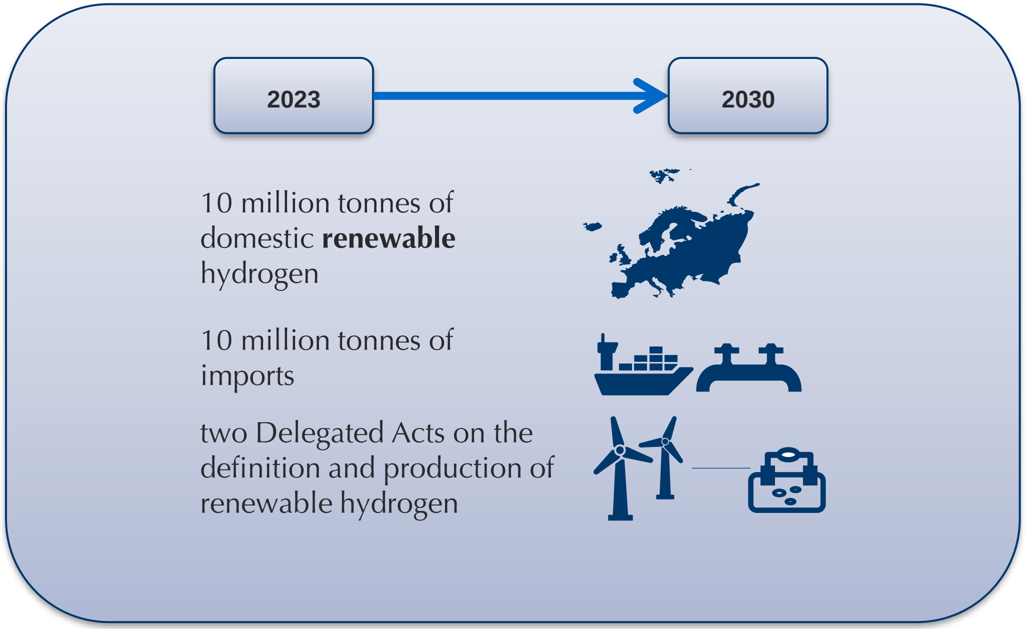
Agenda

Motivation

Providing Spatial Incentives for the H2 ramp-up

- Energy transition in Germany
  - Renewable expansion induces flexibility requirements
  - Regional differences in generation and demand lead to grid bottlenecks from north to south Germany
- Market integration
  - Growing importance of Power-to-Hydrogen (PtH_2) [1]
- Main contribution
  - Analysis of the integration of PtH_2 into zonal electricity markets by use of a decomposed optimization model covering endogenous investment decisions [2]
  - Analysis of CO_2 abatement, renewables integration and regulatory interventions under consideration of H_2-opportunity cost approach [3] instead of exog. H_2-demand



European (H_2-)Strategy in 2030
Source: EU Commission
REPowerEU, 2022; C(2023) 1087 final

1 PtG comprises the conversion of electrical power to hydrogen (PtH2) by electrolysis and to methane (PtM) when further combining it with CO_2
2 Leisen, R.; Böcker, B. and Weber, C.: Optimal capacity adjustments in electricity market models – an iterative approach based on operational margins and the relevant supply stack, Mimeo, 2022;
3 Bucksteeg, M., Mikurda, J., & Weber, C. Integration of power-to-gas into electricity markets during the ramp-up phase—Assessing the role of carbon pricing. Energy Economics, 106805., 2023.

- Benders Decomposition for Des-/Investment Decision
- Iterative adjustment of capacities*

$$\min_{\hat{K}} C_{LT}(\hat{K})$$

$$C_{LT}(\hat{K}) = C_{CPX}(\hat{K}) + C^{*}_{OPX}(\hat{K})$$

$$C^{*}_{OPX}(\hat{K}) = \min_{\hat{y}} C_{OPX}(\hat{y}, \hat{K})$$

$$A\hat{y} + B\hat{K} \geq d$$

- Modelling of H2-demand**

$$\xi^{PtH2}_{a,j,t} = \left(c^{gas}_t + f^{CO2-factor}_{gas} \cdot c^{CO2}_t\right) \cdot \eta_{PtH2}, \text{ or}$$

$$\xi^{PtH2}_{a,j,t} = p^{H2,imp}_t \cdot \eta_{PtH2}$$

- Basic rule of market-oriented operation of domestic electrolyzers:
  - The electrolyzers operate whenever the electricity price is less than or equal to the use value

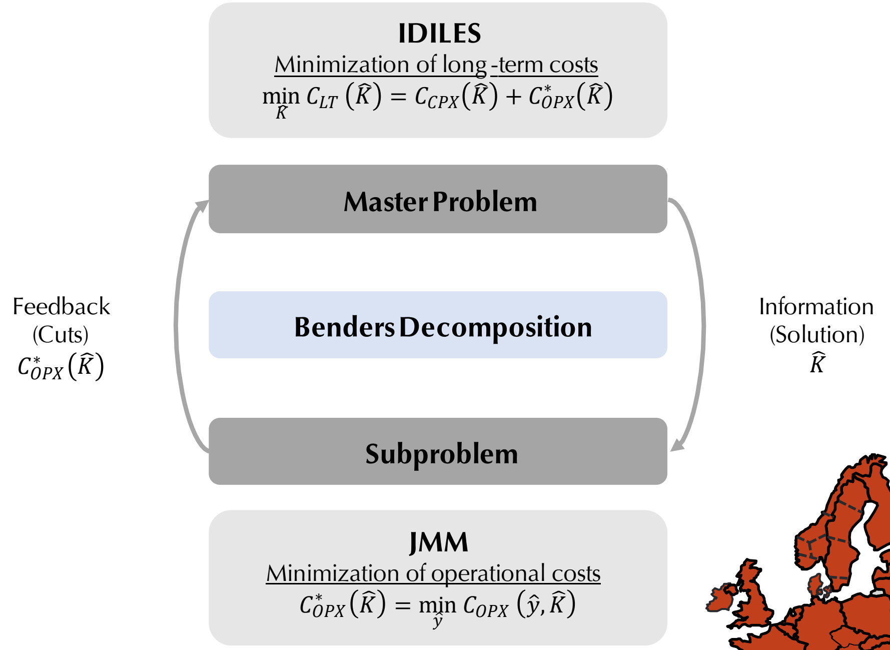
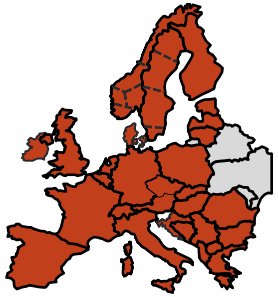


Figure 2: Schematic representation of the Benders decomposition method



* Leisen, R.; Böcker, B. and Weber, C.: Optimal capacity adjustments in electricity market models – an iterative approach based on operational margins and the relevant supply stack, Mimeo, 2022;

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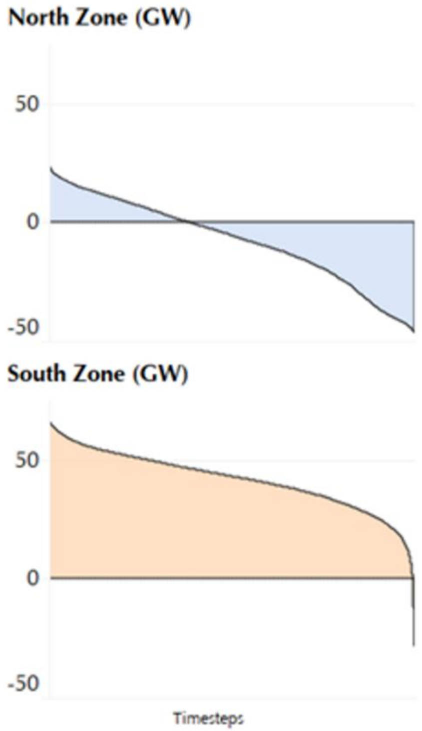
Data

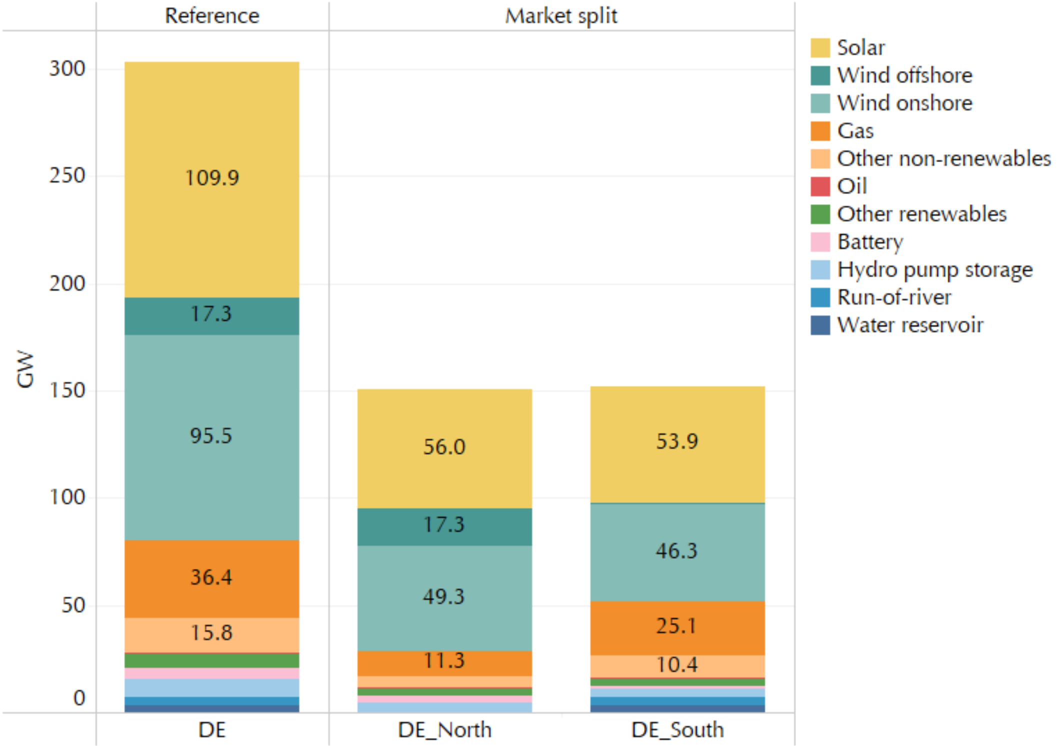
Focus of analysis on Germany, Energy System represents Europe

Zonal Split

Residual Load



Installed Capacity in Germany 2030 (excl. PtH₂)



Data source on Fuel prices, CO_2 prices, Hydrogen, Investment costs and further components:
TYNDP 2020; WEO 2020,2021; Williams et al. 2007; Agora 2018, 2021; Dagdougui et al. 2018; Gorre et al. 2019; IEA 2019; Prognos 2020; Ausfelder and Dura 2021; Hydrogen Council 2021

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Scenarios

Scenarios based on **opportunity cost** of alternative **H_2-production**

- ***SMRdom*** – alternative: steam reforming
  - more reflective of an early transition stage where PtH_2 may penetrate the market by partly substituting conventional hydrogen obtained via steam reforming
- ***GreenImp*** – alternative: Green hydrogen imports
  - focuses on the build-up of a "pure play" green hydrogen infrastructure, where business cases building on domestic and imported green hydrogen are in competition

Sensitivities

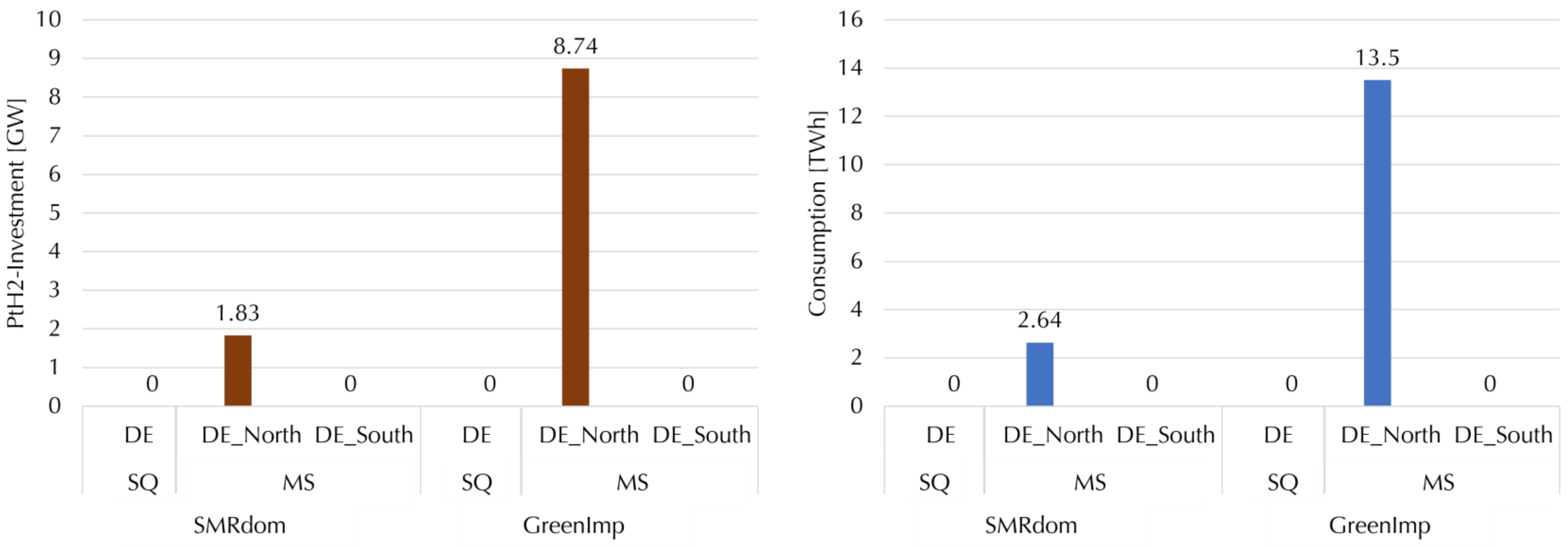
- Investment abroad
- Regulatory aspects
  - Supplementary delegated act (additionality criterion)

Driver for use value → / **Bidding zone configuration** ↓		**Steam reforming**	**Green hydrogen imports**
	Reference run	*SMRdom*	*GreenImp*
Status quo *SQ*	*SQ_0*	*SQ_SMRdom*	*SQ_GreenImp*
Market split *MS*	*MS_0*	*MS_ SMRdom*	*MS_ GreenImp*

Impact of Market Splitting on Investment Incentives and Prices (1/2)

Results

Electrolyzer investment and consumption in 2030



- Investment into electrolyzer only in MS-scenarios
  - MS_SMRdom < MS_GreenImp
  - Solution is a consequence of different price distributions in the different market zones…
  - and the different use values between MS_scenarios

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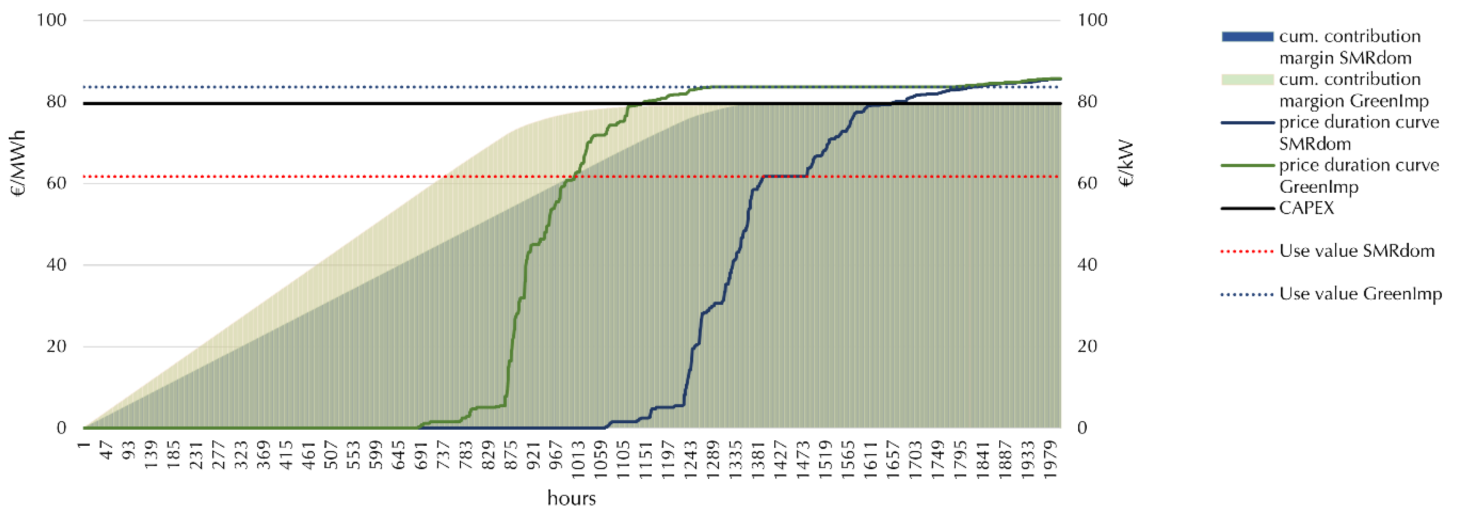
Impact of Market Splitting on Investment Incentives and Prices (2/2)

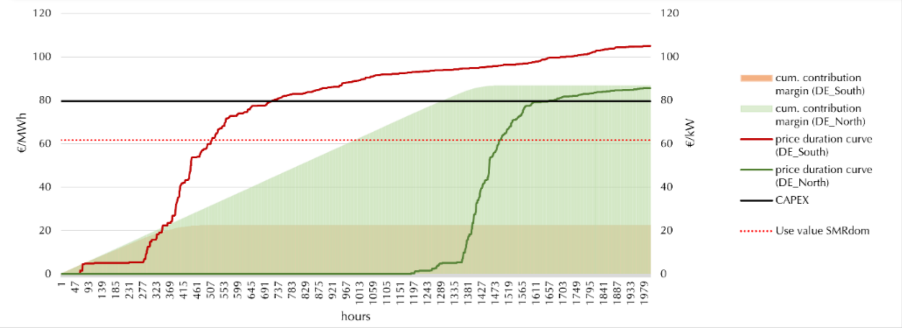
Results

Details of the price duration curves and profitability of electrolyzers in DE_North in the scenarios MS_SMRdom and MS_GreenImp



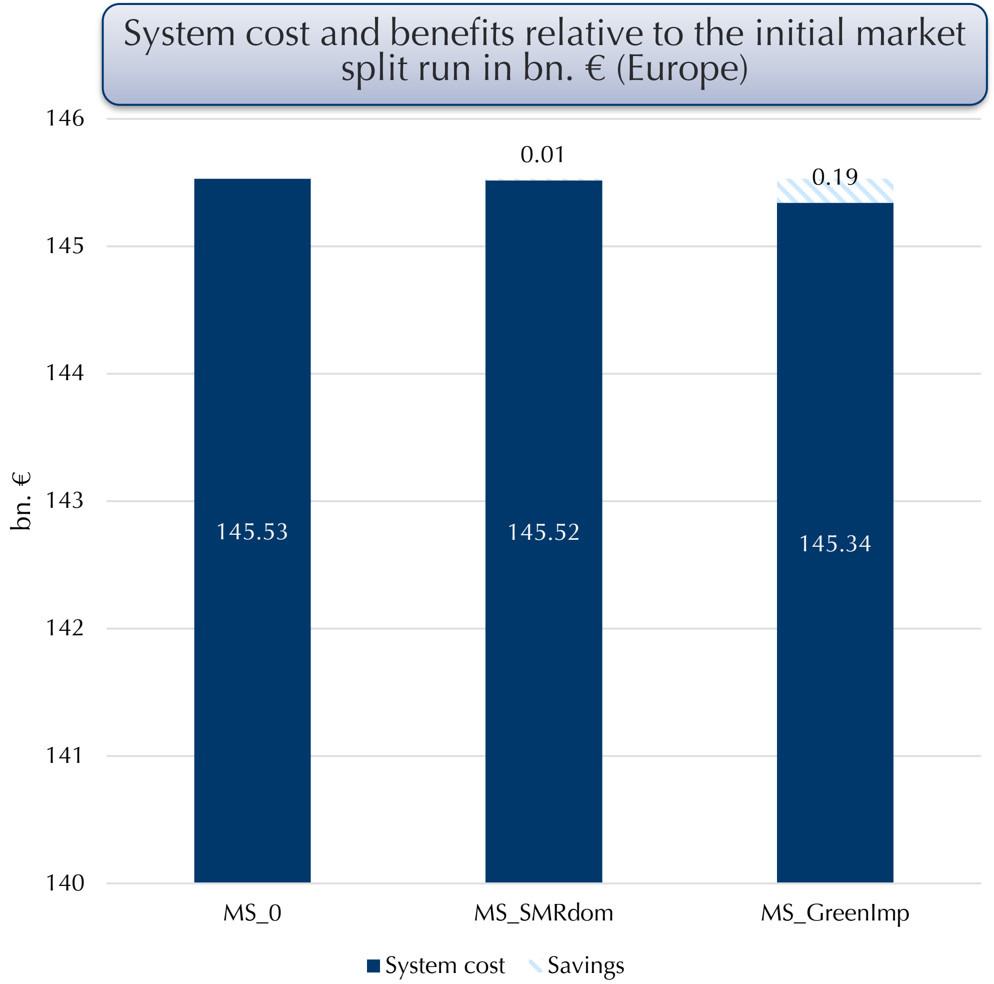
- *MS_GreenImp*-price duration curve is left-shifted with lower utilization hours compared to *MS_SMRdom*
  - higher installed electrolyzer capacity absorbs more excess renewable energy and thus modifies the dispatch of plants and pushes up the prices

Details of the price duration curves and profitability of electrolyzers in **DE_North and DE_South** in the scenario MS_SMRdom for the initial run MS_0



System Costs

Results

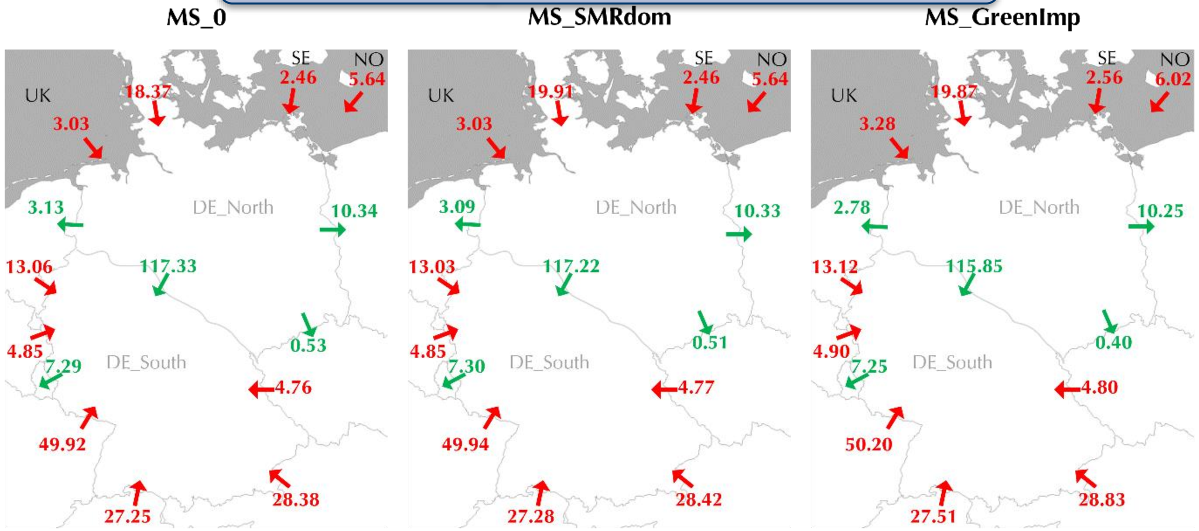


- Initial market split run *MS_0* provides reference
- Investments in electrolyzers induce savings in system cost
  - About 190 M€ in the *MS_GreenImp* scenario

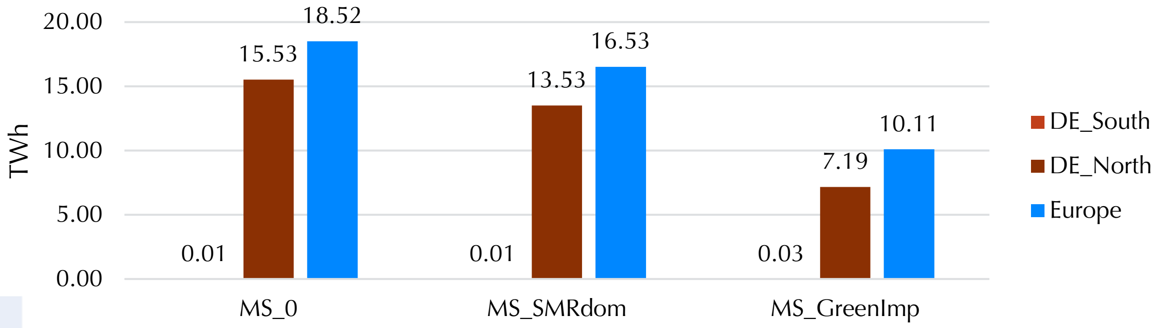
Impacts on Congestion, Emissions and Renewable Integration

Results

Germany's annual electricity exchange with neighboring countries



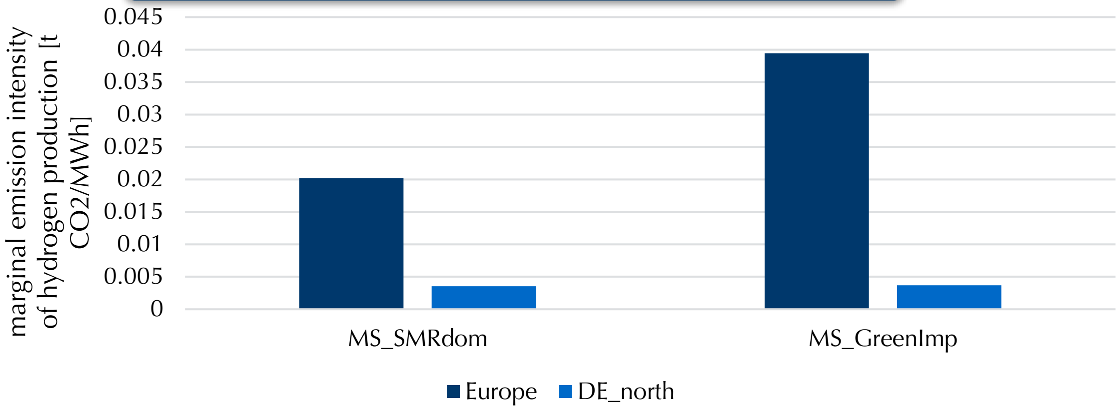
Renewable curtailment



Installation of electrolyzers in Germany

- has only **limited impacts** on the **cross-border** energy exchanges
- **reduces renewable curtailment** in northern Germany
- implies a **slight increase** in electricity production from local **conventional plants** in northern Germany
- induces a **small increase in emissions**

CO2 intensity per unit of H2 produced



CO_2 emission intensity of steam reforming:
7.5 to 12 tons of CO_2 per ton of hydrogen, i.e. 0.22-0.36 tCO2/MWh

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Conclusion

- **Key issue**:
  Deployment of PtH_2 during the energy transition under consideration of **uncertainties** (H_2 pricing) and **system related issues** (north-south-bottlenecks)
- **Main contribution**:
  Shed a light on **market splitting** to understand **investment and dispatch incentives** for the deployment of **PtH_2** into the electricity markets – and further understand **system feedback effects**
- **Results**:
  - **Market split** provides in mid-term (2030) already **sufficient incentives** for market-driven electrolyzer investments
  - Electrolyzer operation only induces **very limited increases in CO_2 emissions** and the produced hydrogen qualifies as “low carbon” hydrogen
  - **locational signals** for deployment and operation of the electrolyzers **induce benefits** for the system regarding costs as well as curtailment of renewables

➢ As an adequate split of bidding zones strengthens investment incentives, this also leads to a **reduction of uncertainty among investors** - correspondingly the **system transformation** may **speed up**

Thank you for your attention!

Marco Sebastian Breder
Team Energy Markets and Energy Policy
House of Energy Markets and Finance
University of Duisburg-Essen
R11 T07 C02 | Universitätsstraße 12 | 45141 Essen | Germany
Tel. +49 201/18-36459 | Fax +49 201/18-32703
Email: Marco.Breder@uni-due.de
www.ewl.wiwi.uni-due.de

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