MODEZEEN H_2-Workshop Model analysis – Focusing on the impact of market splitting on power-to-hydrogen

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Open-Minded

Agenda

Motivation

- 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 incentives through CO_2 pricing and market splitting

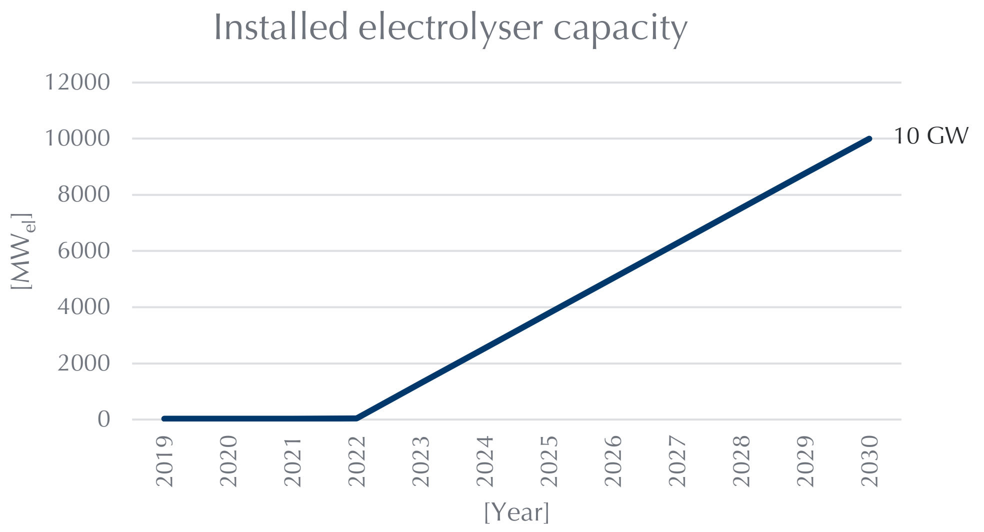

Figure 1: Planned electrolyser capacity in Germany in 2030
Source: Bundesregierung (2021)

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; Bucksteeg, M.; Mikurda, J. and Weber, C.: Integration of power-to-gas into electricity markets during the ramp-up phase – Assessing the role of carbon pricing, Working Paper, http://hdl.handle.net/10419/242982, 2022.

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Methodology

Market model overview

- Joint market model (JMM)
  - Linear problem with hourly resolution
  - System cost minimization
  - Decision variable: dispatch
  - Modelling of Day-ahead electricity markets, balancing markets and heat markets
- IDELES: Benders Decomposition for Des-/Investment Decision (work in progress)
  - General Approach
    - Iterative adjustment of capacities
    - Based on the subgradient method of optimization
    - Two-level problem

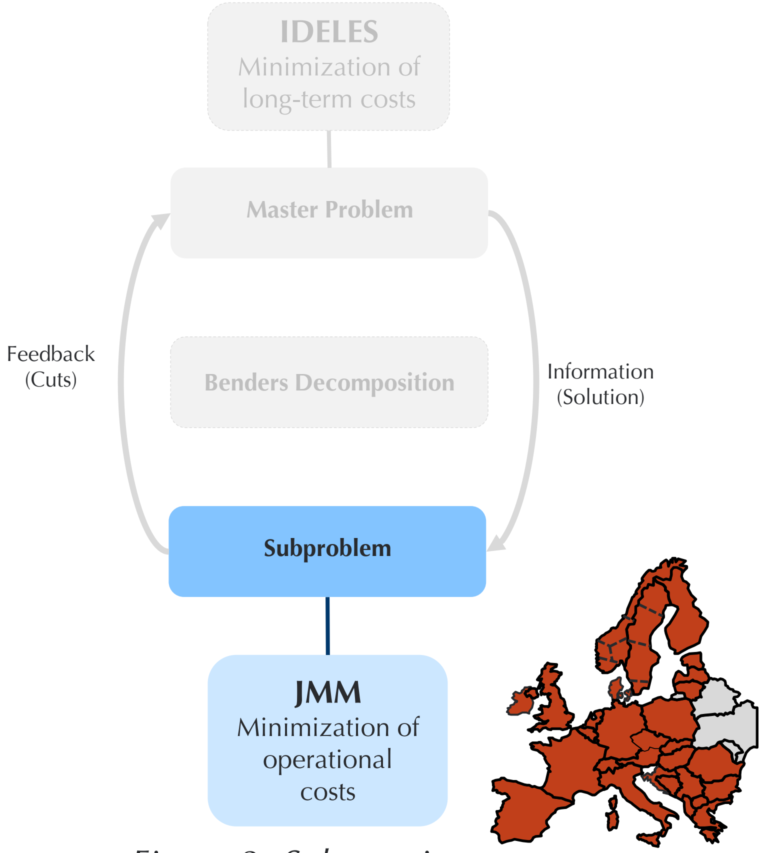

Figure 2: Schematic representation of the Benders decomposition method

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

Utilization of Power-to-Hydrogen in electricity markets

General considerations

- Calculus of the dispatch decision
  – Definition of the value of the converted gas, i.e. use value
  – Utilization of the electrolyser when electricity price is lower than (or equal to) the use value
- No exogeneous H_2-Demand necessary
  – Advantage: Endogenous decision of production based on market incentives
- General effects of market split and CO_2-Pricing on PtH_2-utilization:

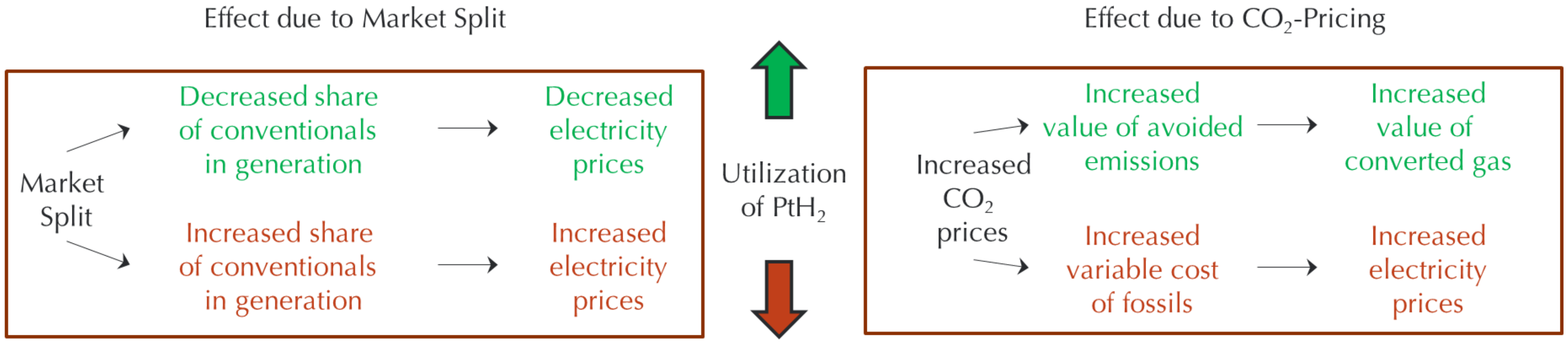

Figure 3: Effects of Market Split and CO_2-Pricing on PtH_2-Utilization

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Bucksteeg, M.; Mikurda, J. and Weber, C.: Integration of power-to-gas into electricity markets during the ramp-up phase – Assessing the role of carbon pricing, Working Paper, http://hdl.handle.net/10419/242982, 2022.

Market Split of Germany

Demonstration of North-South Bottleneck

- Simplified deduction of two zones:
  - OSMOSE[3] nodal price study results indentify a price differential between north and south
- Implementation:
  - Market split along federal state borders due to reasonable data availability
  - Underlying data sources:
    - Grid data information obtained from TYNDP
    - Regional RES infeed and demand timeseries:
      - Capacities on county level (NUTS3) taken from OSMOSE[3]
      - Then scaled to match TYNDP timeseries on national level (NUTS0)
      - County timeseries in south and north added up to obtain regional timeseries

Zonal Split

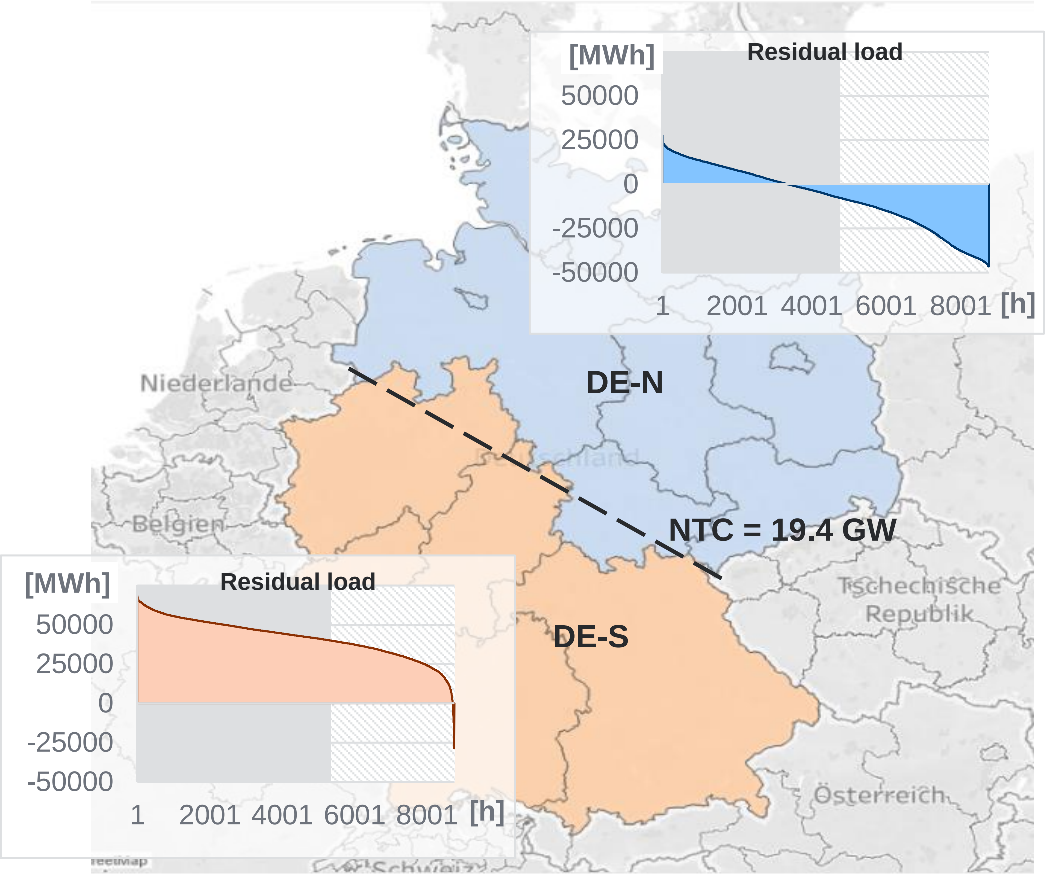

Figure 4: Regional Split Germany

[3] OPTIMAL SYSTEM MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY (OSMOSE); WP1 https://www.osmose-h2020.eu/

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Input data and Scenarios

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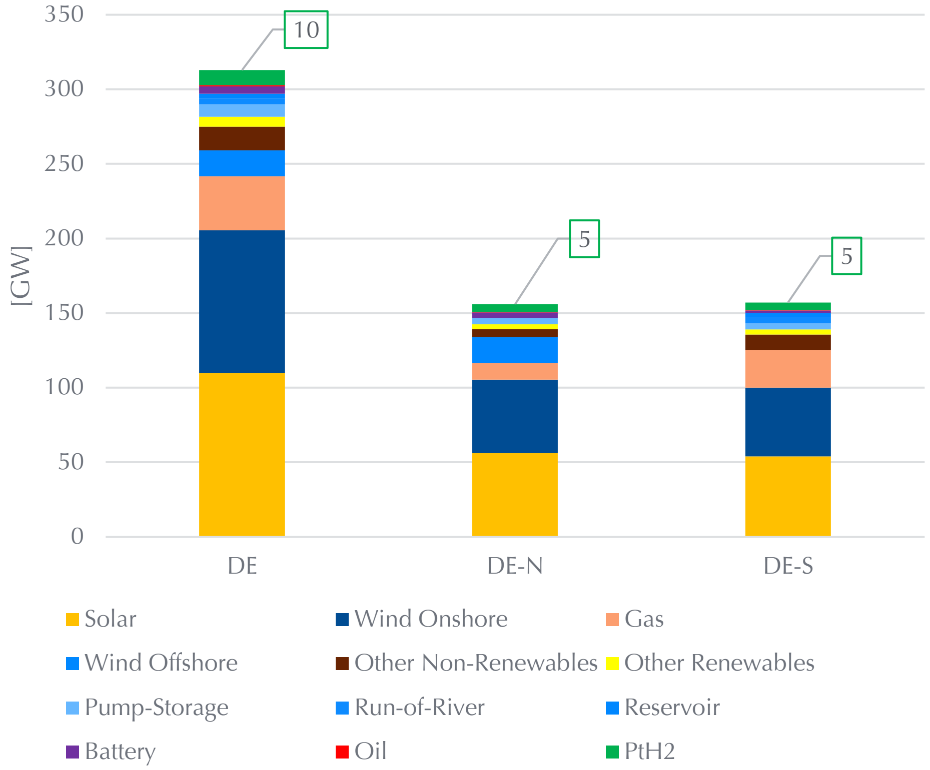
- TYNDP 2020 - Distributed Energy
  - Generation Portfolio
  - Production
  - NTCs

Scenarios		DE_75 / DE_S/N_75	DE_114 / DE_S/N_114
CO$_2$ Price	€/tCO$_2$	75.00	114.00
Fuel costs			
Natural Gas	€/MWh$_{th}$	24.88	24.88
Oil	€/MWh$_{th}$	73.80	73.80
Coal	€/MWh$_{th}$	15.48	15.48
Use value			
PtH$_2$	€/MWh$_{el}$	79.94	90.31

Installed Capacity in Germany including PtH$_2$ [2030]



[1] Other Non-Renewables: Mainly smaller scale CHPs based on Oil and Gas
[2] Other Renewables: Mainly Biomass and Municipal Waste

*DE_75, DE_114 are scenarios with one market zone in Germany
DE_S/N_75, DE_S/N_114 are scenarios with two market zones in Germany (North-South)

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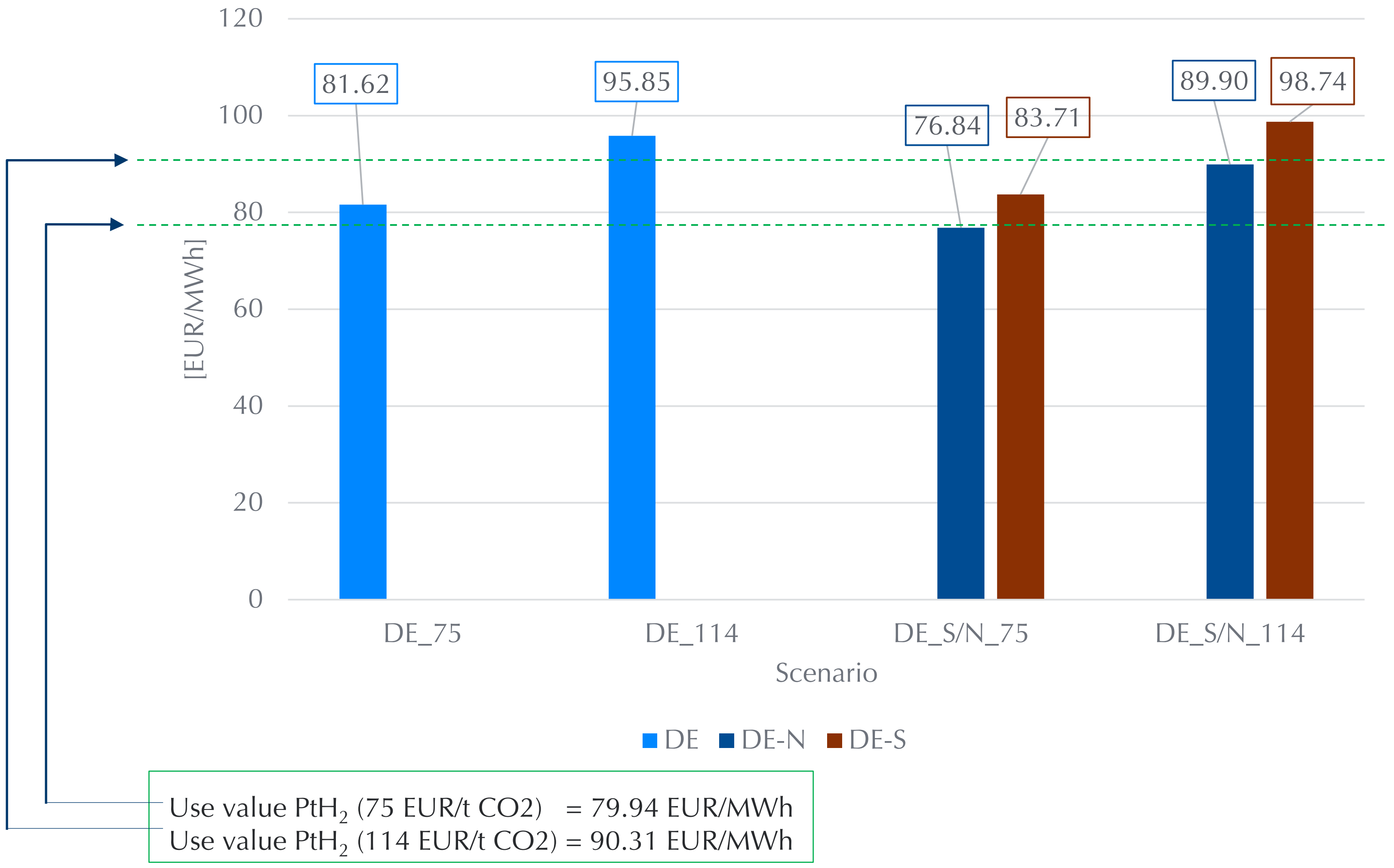
Dayahead-Mean Prices

- Prices mainly affected by conventional production (i.e. natural gas)
- Zonal split leads to lower prices in north compared to south due to higher shares of RES and less demand
- Lower prices in DE-North incentivize utilization of PtH_2 → prices are below the use value in several hours of the year



H_2-Results with 75 EUR/t CO_2

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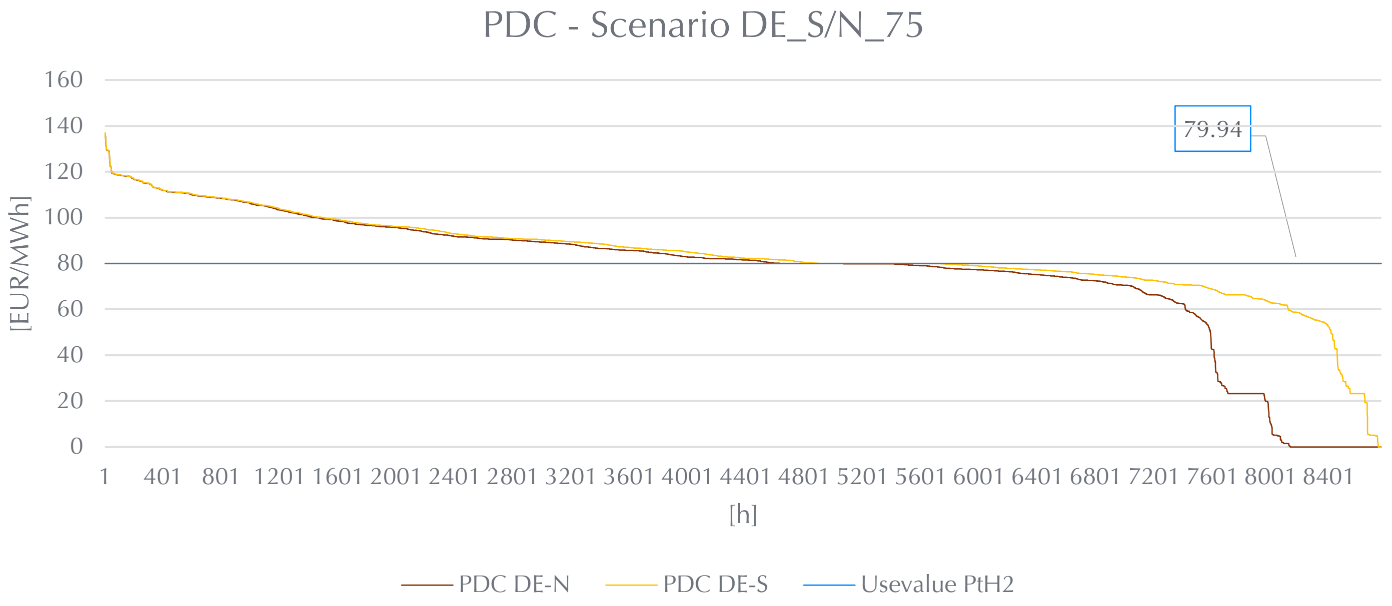
- More fullload hours in north compared to south
  - Due to more hours with prices below corresponding use values
- One-Zone vs. Two-Zone Scenario
  - Electrolysers show 0.63 TWh higher production in Two-Zone scenario
  - Positive effect of split at moderate CO_2-Prices
- Effect of CO_2-Pricing
  - High operating costs of conventionals are less relevant in north due to high shares of fluctuating renewables in regional generation mix

Scenarios		DE_75	DE_114	DE_S/N_75		DE_S/N_114	
Region		DE	DE	DE-N	DE-S	DE-N	DE-S
Operating Hours	[h]	3832	3752	4085	3515	4114	3120
Fullload Hours	[h]	2560	2501	2843	2401	2841	2118
Production PtH_2	[TWh]	25.60	25.01	14.22	12.01	14.21	10.59



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H_2-Results with 114 EUR/t CO_2

- More fullload hours in north compared to south
  - This time the difference increases while the level in the north is constant
- One-Zone vs. Two-Zone Scenario
  - One-Zone scenario has 0.2 TWh higher H_2-production in total
  - Negative effect of CO_2 price on total H_2-production in Two-Zone Scenario
- Focus on Two-Zone-Scenarios
  - H_2-production in the south is negatively affected by high CO_2 prices
  - Incentive for redistribution due to (dis-)advantage of location

Scenarios		DE_75	DE_114	DE_S/N_75		DE_S/N_114	
Region		DE	**DE**	DE-N	DE-S	**DE-N**	**DE-S**
Operating Hours	[h]	3832	**3752**	4085	3515	**4114**	**3120**
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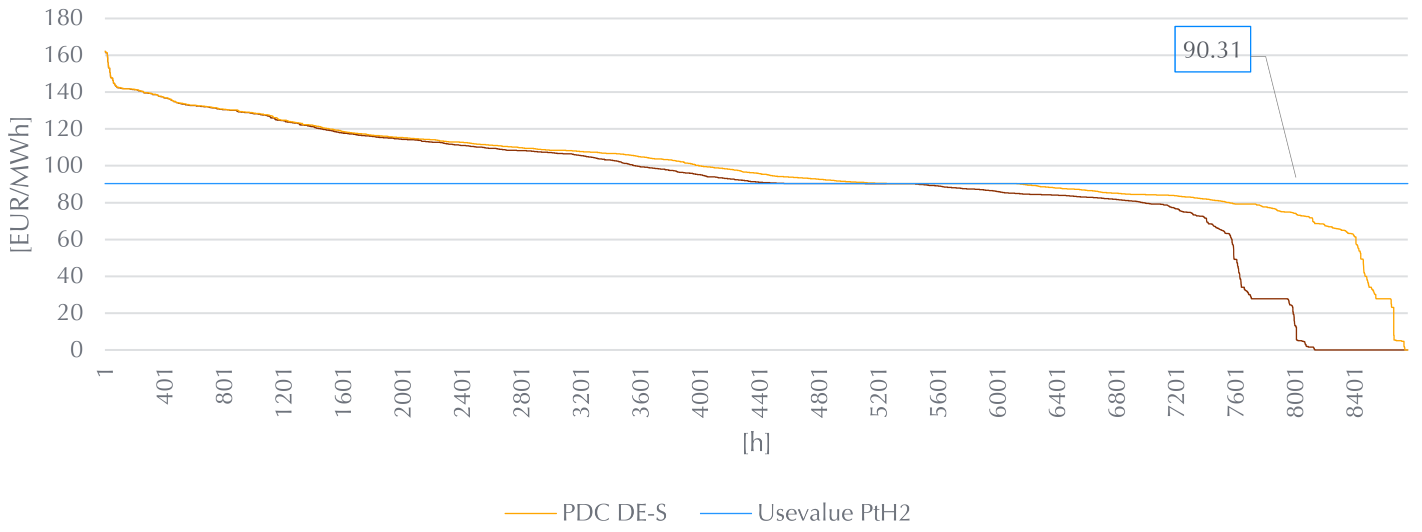
PDC - Scenario DE_S/N_114



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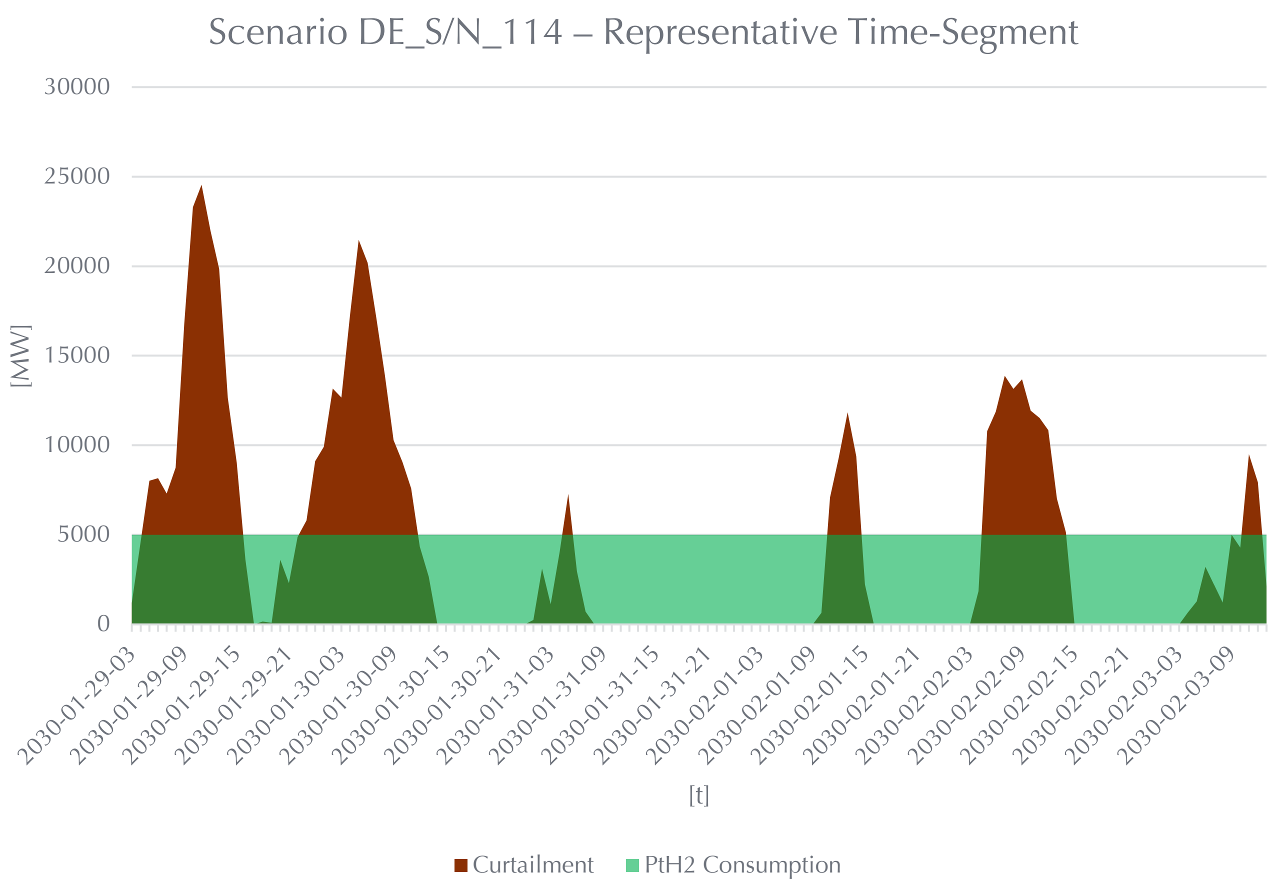
Hourly Curtailment and PtH_2 Consumption in north germany

- 590 hours of curtailment
- Shedded energy 6.2 TWh
  - Surplus production cannot be used from PtH_2 due to capacity limit of 5 GW in these scenarios (without IDELES)
  - NTC to DE-S at capacity limit
  - No statement regarding electrolyser distribution possible
- ➢ Further analysis with IDELES necessary to investigate potential investment incentives for PtH_2



Conclusion

- **Key issue**: Integration of PtH_2 during the energy transition, but regulatory barriers (especially due to inconsistent pricing of CO_2 emissions) and system related issues (north-south-bottlenecks)
- **Main contribution**: shed a light on CO_2 pricing and market splitting to understand investment and dispatch incentives in the integration of PtH_2 into the electricity markets
- **Results**:
  - Market split incentivizes higher utilization of PtH_2 in North Germany due to a higher share of RES
  - Together with increased CO_2 prices incentives for PtH_2 utilization become even higher in North Germany due to conventional generation technologies being price setting in South Germany
  - However, effects are limited by the exogenous distribution of electrolyser capacity under the market split

➢ Further analysis using **IDELES** with endogenous investment decisions will show how the observed market signals influence the integration of PtH_2

Thank you for your attention!

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