Market integration of Power-to-Gas during the energy transition – Assessing the role of carbon pricing

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Motivation

- Energy transition
  - Renewable expansion induces flexibility requirements
  - Generation mix transitionally based on conventional technologies
- Market integration
  - Growing importance of Power-to-Gas (PtG) [1]
  - BUT: lack of consistent incentives
- Main contribution
  - Extension of an optimization model covering electricity and heating markets by PtG
  - Analysis of different regulatory settings regarding levies and CO_2 pricing

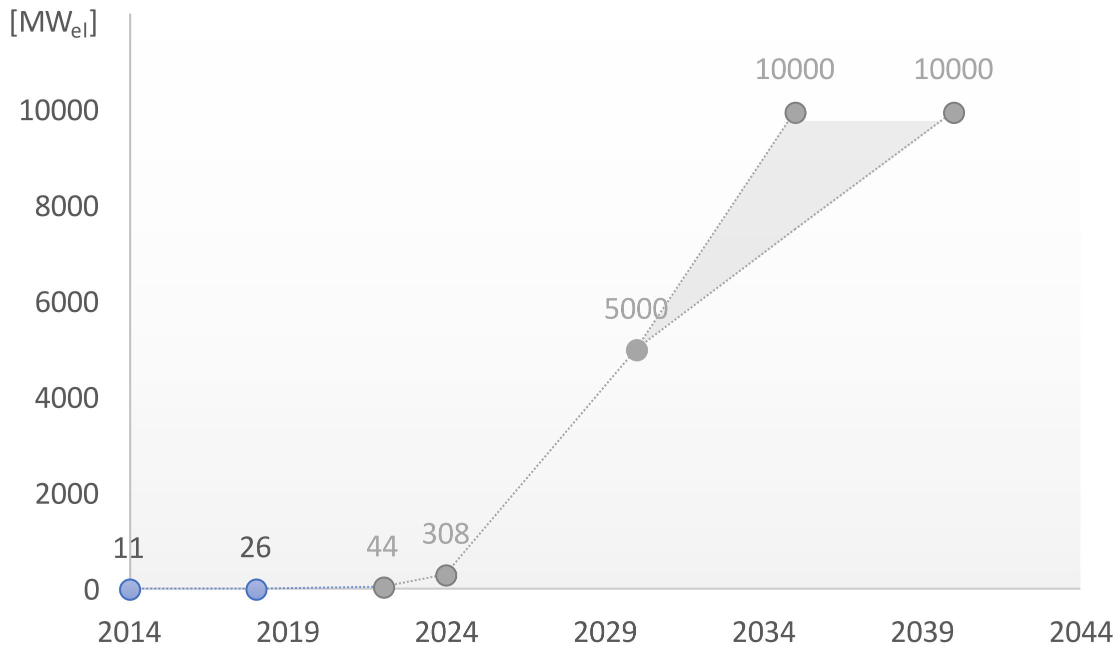

Figure 1: Installed and planned electrolyser capacity in Germany
Sources: DVGW (2020), TÜV SÜD (2020), BMWi (2020)

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1 PtG comprises the conversion of electrical power to hydrogen (PtH2) by electrolysis and to methane (PtM) when further combining it with CO_2

- Calculus of the dispatch decision
  - Definition of the value of the converted gas*, i.e. use value

$$c_t^{PtG,use} = \left(c_t^{fuel} + f_{fuel}^{CO2-factor} \cdot c_t^{CO2}\right) \cdot \eta_{PtG}$$

  - Utilization of the electrolyser when electricity price is lower than (or equal to) the use value

$$\lambda_t^{el} + \pi_t - c_t^{PtG,use} \geq 0 \perp W_t^{DA} \geq 0$$

  - Electricity price is determined by variable generation costs of the marginal technology

$$\lambda_t^{el} = \frac{c_t^{fuel} + f_{fuel}^{CO2-factor} \cdot c_t^{CO2}}{\eta_u} + c_u^{O\&M}$$

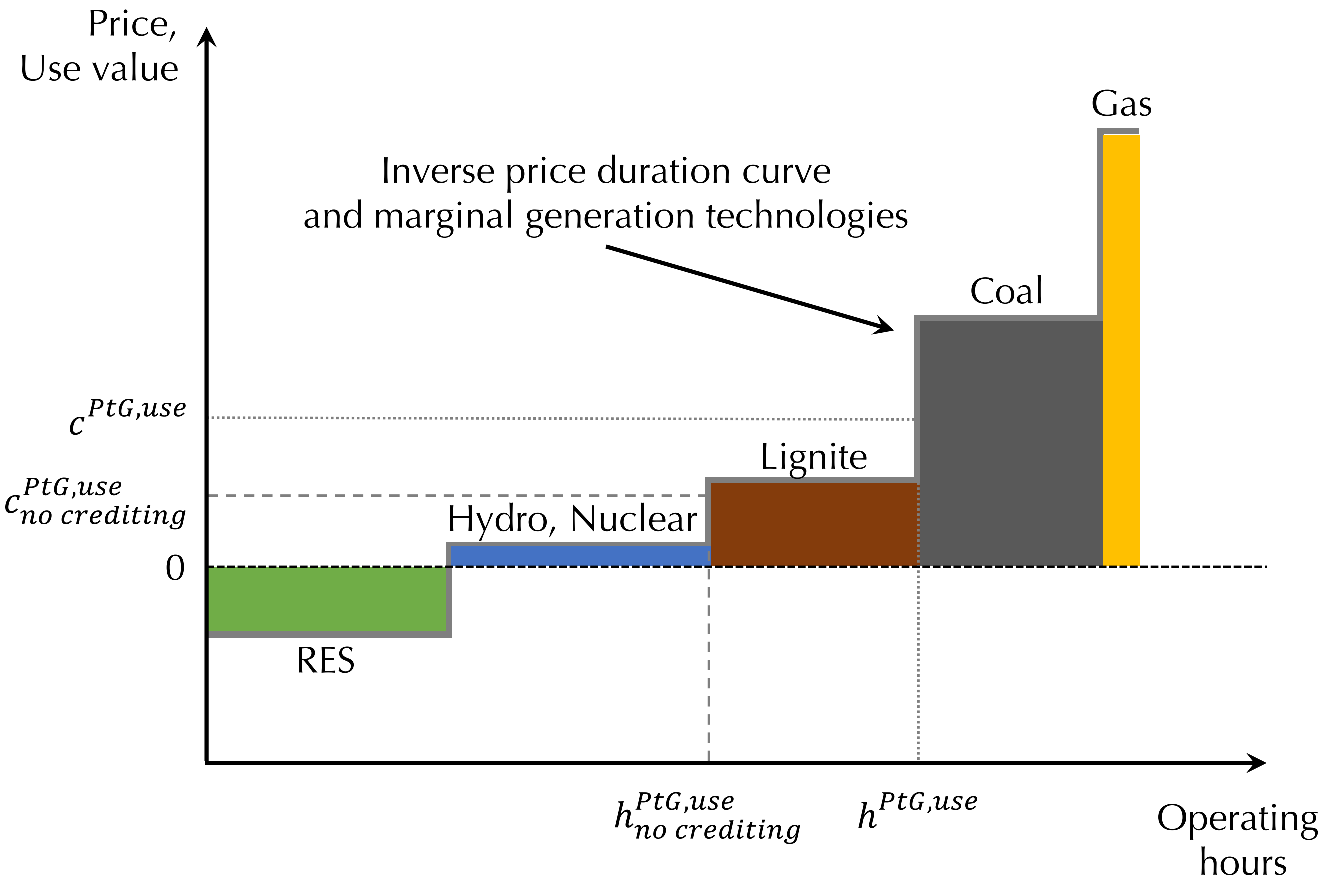

Figure 2: Schematic representation of the utilization of PtG

* See also Böcker and Weber (2015)

Carbon pricing and Power-to-Gas

General considerations

- Calculus of the dispatch decision
  - Definition of the value of the converted gas, i.e. use value

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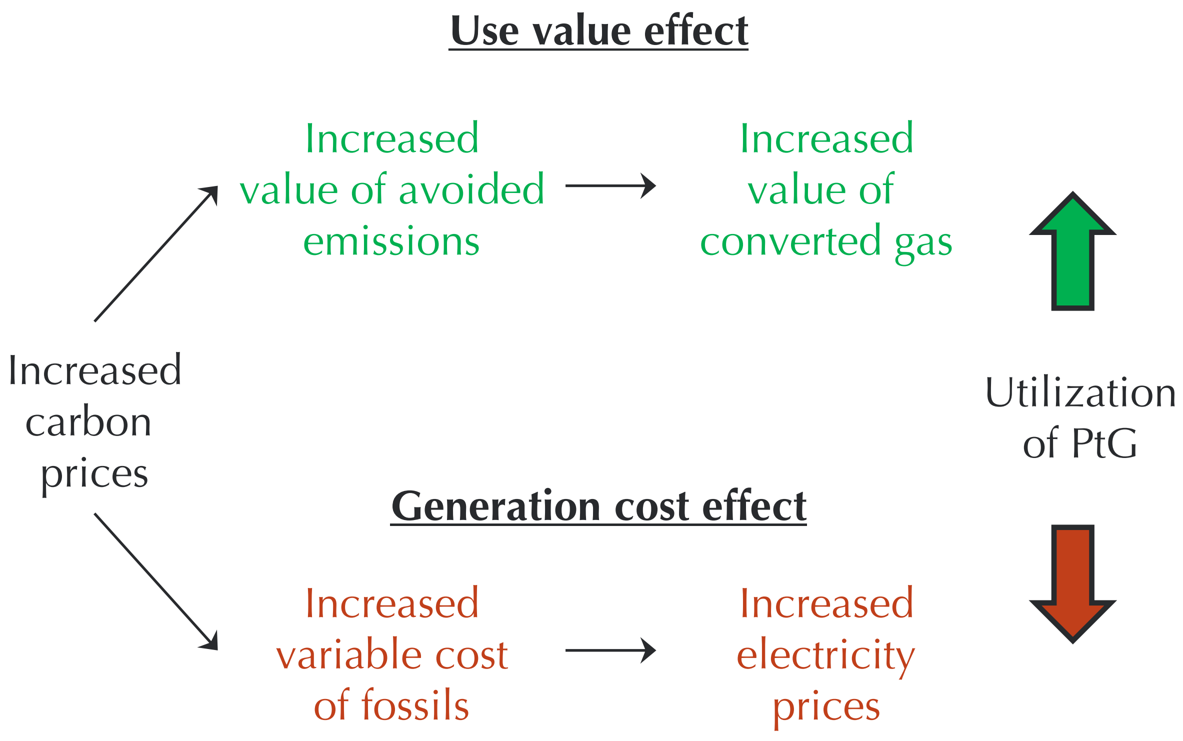


Figure 3: Effects of carbon pricing on PtG utilization

Methodology

Market model overview

- Joint market model (JMM)
  - Linear problem with hourly resolution
  - min (system costs)
  - Subject to side constraints
    (1) Demand restriction
    (2) Balance equations
    (3) Transmission constraints
    (4) Technical restrictions
  - Decision variable: dispatch
  - Modelling of Day-ahead electricity markets, balancing markets and heat markets

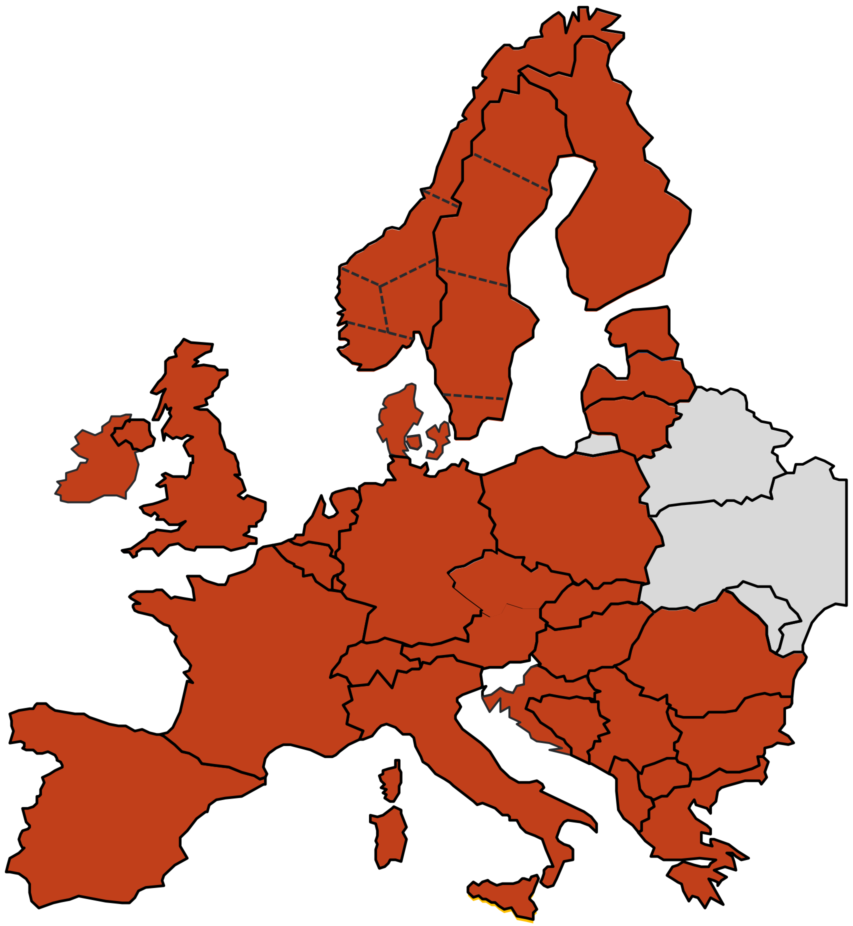


Figure 4: Geographical coverage of the JMM

Methodology

Model extension PtG

- Modelling of PtG in the JMM
  - Process can be interpreted as filling of a virtual storage:
    1) Utilization of the electrolyser leads to additional electricity consumption $W_{t,a,i}^{DA}$
    2) Electricity is converted to gas subject to conversion losses (i.e. conversion rate $\eta_{a,i}$)
    3) Synthetic gas is then fed into the gas network
    4) Extraction from the gas network $P_{t,a,i}^{PtG}$
    - ➢ Balance equation: $V_{t,a,i}^{PtG} = V_{t-1,a,i}^{PtG} + \eta_i \cdot W_{t,a,i}^{DA} - P_{t,a,i}^{PtG}$
  - Further model adaptions:
    - Constraints limiting virtual storage content and electricity consumption including provision of control reserves
    - Objective function: addition of the use value
    - Demand restriction: addition of electricity consumption of the electrolyser

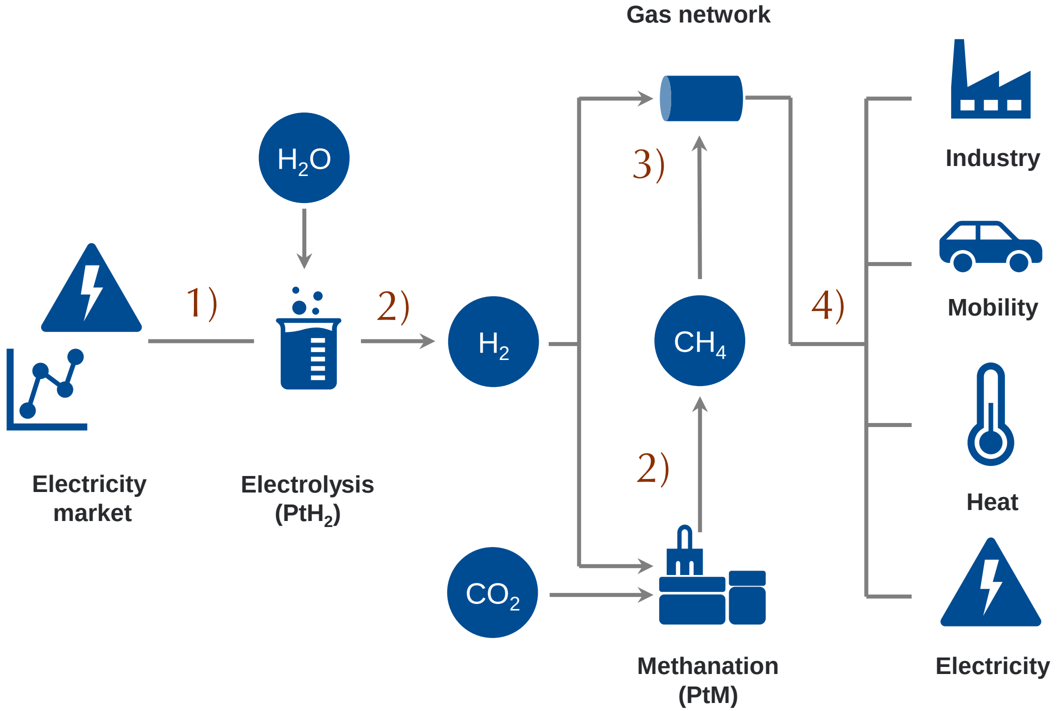


Figure 5: Schematic representation of the PtG process

- Scenario characteristics
  - European electricity market in 2025 with a focus on Germany
  - Based on TYNDP Best Estimate Scenario 2025
  - Fuel prices based on recent futures prices for 2022
  - Electrolysers exempted from EEG levy
- Power-to-Hydrogen (PtH_2)
  - 2 GW installed capacity, 73 % conversion rate
  - Application: mobility
- Power-to-Methane (PtM)
  - 2 GW installed capacity, 60 % conversion rate
  - Application: replacement of natural gas

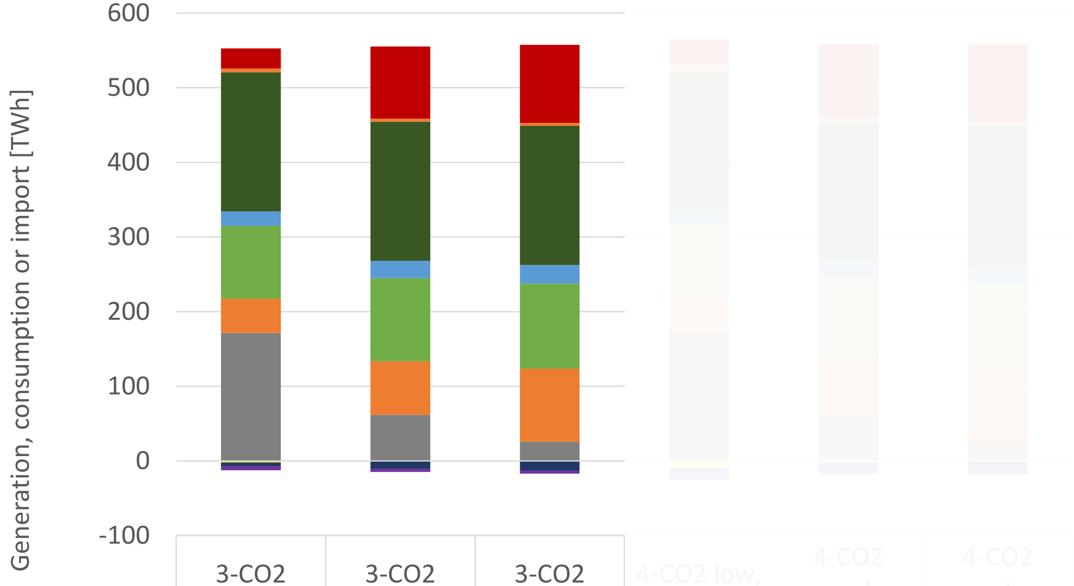
Scenario		Status-quo	Moderate	Ambitious
CO_2 price	€/tCO_2	26.00	66.75	107.50
Marginal costs				
Lignite	€/MWh_{el}	28.80	67.73	106.66
Hard Coal	€/MWh_{el}	44.15	78.20	112.25
Natural Gas	€/MWh_{el}	53.03	69.73	86.43
Use value *without* CO_2 crediting				
PtH_2	€/MWh_{el}	40.87	40.87	40.87
PtM	€/MWh_{el}	12.72	12.72	12.72
Use value *with* CO_2 crediting				
PtH_2	€/MWh_{el}	47.48	57.85	68.20
PtM	€/MWh_{el}	18.18	26.64	35.16

Table 1: Scenario matrix: CO2 prices, marginal costs and use values

Results and Discussion

System and market perspective

- Status quo, without CO_2 crediting:
  - Utilization of PtH_2 of ~1000 h/year, but only 20 h/year for PtM (see also 3-CO2 low)
- Impact of increasing CO_2 prices:
  - Lower utilization of coal, which is balanced by generation from gas and imports
  - Reduced utilization/consumption of PtG
    → Generation cost effect



	3-CO2 low	3-CO2 mod	3-CO2 amb	4-CO2 low, crediting	4-CO2 mod, crediting	4-CO2 amb, crediting
DSM Cons	-5.2	-4.0	-4.1	-10.3	-5.3	-4.8
Pump Storage Cons	-5.5	-10.7	-13.0	-5.4	-10.5	-12.9
PtG Cons	-1.9	-0.1	-0.1	-9.0	-2.0	-1.1
Import	26.9	96.6	104.6	32.0	98.2	105.6
DSM	5.2	4.0	4.1	10.3	5.3	4.8
Wind & Solar	186.4	186.4	186.4	186.4	186.4	186.4
Hydro	19.3	23.2	24.9	19.2	23.1	24.9
Bioenergy & Other	97.8	111.6	114.1	97.8	111.6	114.1
Natural Gas	46.0	72.0	97.9	46.7	72.0	98.0
Lignite & Coal	171.3	61.5	25.5	172.4	61.5	25.5

Figure 6: Generation and import for Germany in 2025 (Cons: consumption of flexibilities)

Results and Discussion

System and market perspective

- Status quo, without CO_2 crediting:
  - Utilization of PtH_2 of ~1000 h/year, but only 20 h/year for PtM (see also 3-CO2 low)
- Impact of increasing CO_2 prices:
  - Lower utilization of coal, which is balanced by generation from gas and imports
  - Reduced utilization/consumption of PtG → Generation cost effect
- Impact of crediting of avoided CO_2 emissions:
  - Higher utilization of PtG → Use value effect
  - In case of low CO_2 prices PtG consumption is supplied by imports and generation from coal (see 4-CO2 low, crediting)

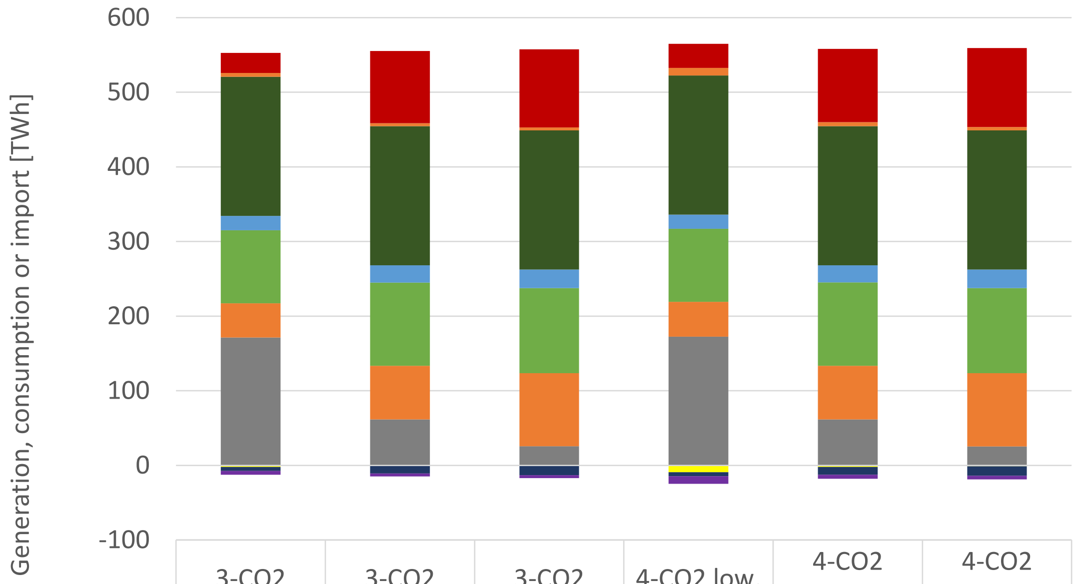


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*Figure 6: Generation and import for **Germany** in 2025 (Cons: consumption of flexibilities)*

Results and Discussion

System and market perspective

- Increasing CO_2 prices
  - Reductions of CO_2 emissions for Germany are in line with the impacts on the generation mix
  - Due to the coal-gas-switch emissions reductions for the moderate scenario are relatively higher
- Crediting of avoided CO_2 emissions
  - Higher CO_2 emissions driven by increased consumption from PtG and generation from lignite and hard coal
  - This effect disappears in case of high CO_2 prices

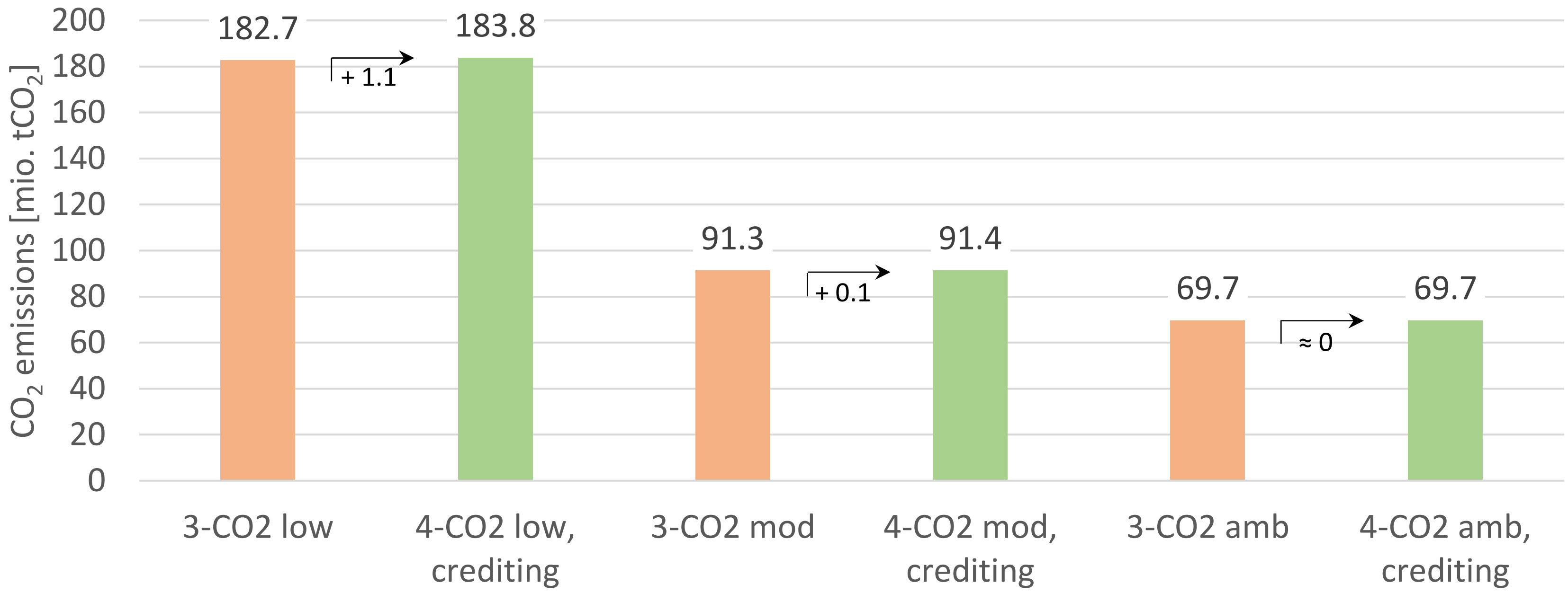

Figure 7: CO2 emissions for Germany in 2025

Results and Discussion

Interactions between CO_2 prices and PtH2

- Low CO_2 price (CO_2 low):
  - Crediting of avoided CO_2 emissions increases the use value and leads to a high utilization of 4641 h/a
  - BUT: flat price duration curve with coal plants being marginal in most of the time
  - ➢ Use value effect dominates generation cost effect
- High CO_2 price (CO_2 amb):
  - CO_2 crediting increases utilization of PtH_2 to 629 h/a
  - BUT: increase is limited by the steeper price duration curve
  - ➢ Generation cost effect balances use value effect

➢ Crediting of avoided CO_2 emissions supports the integration of PtH_2, but can be environmentally questionable depending on the CO_2 price level

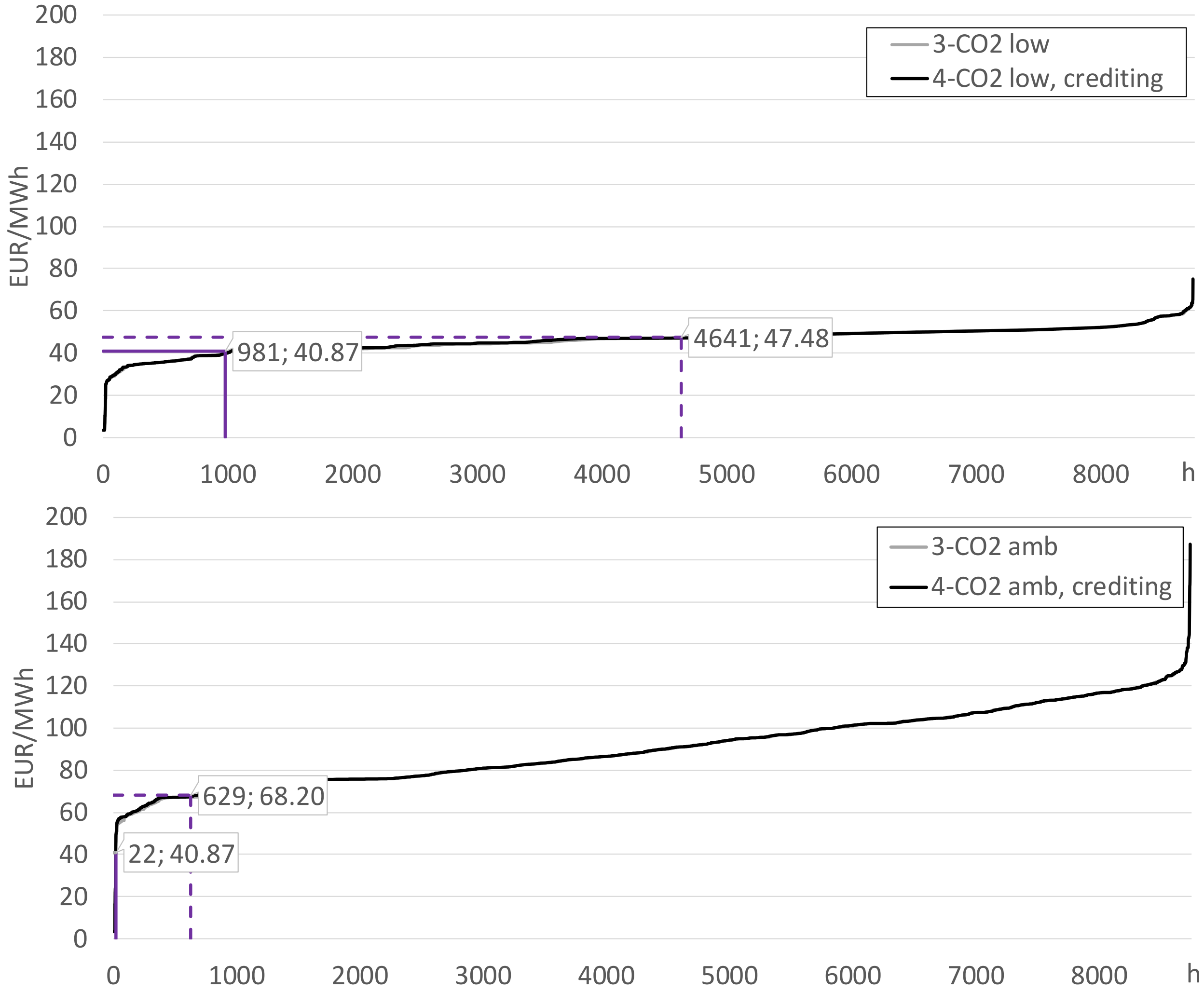

Figure 8: Inverse price duration curves and utilization of PtH_2

Conclusion

- **Key issue**: Growing importance of Power-to-Gas (PtG) during the energy transition, but regulatory barriers due to levies and inconsistent pricing of CO_2 emissions
- **Main contribution**: shed a light on different regulatory settings regarding levies and CO_2 pricing and their implications for the integration of PtG into the electricity markets
- **Results**:
  - Electrolysers being exposed to the EEG levy PtG are not utilized (see Appendix)
  - Increasing CO_2 prices induce decreased utilization of PtG → Generation cost effect
  - Crediting of avoided CO_2 emissions supports the integration of PtG → Use value effect

➢ An improved regulatory framework, e.g. EEG exemption and CO_2 crediting, can help to integrate PtG into electricity markets, but might lead to adverse effects on CO_2 emissions when CO_2 prices are too low

Thank you for your attention!

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