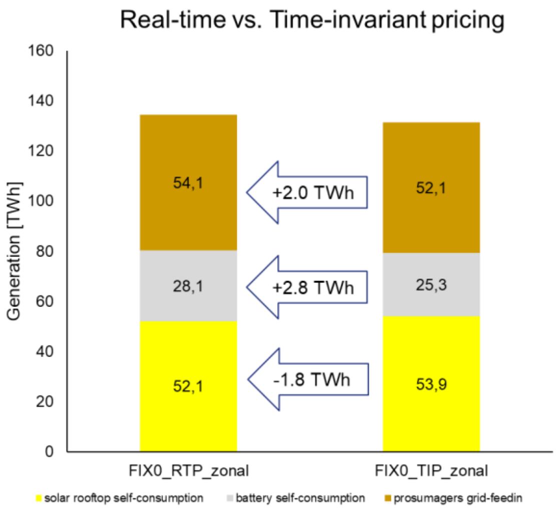

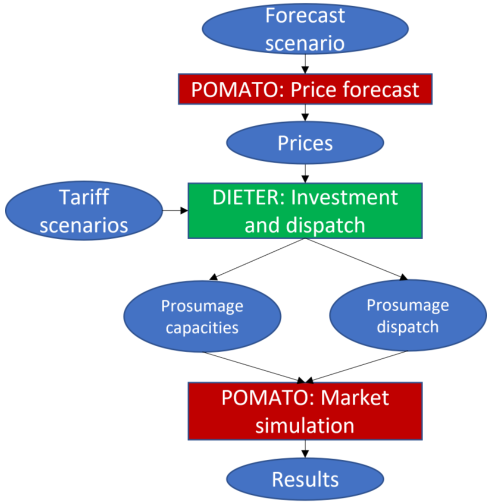

Solar prosumage: Interactions with the transmission grid

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Outline

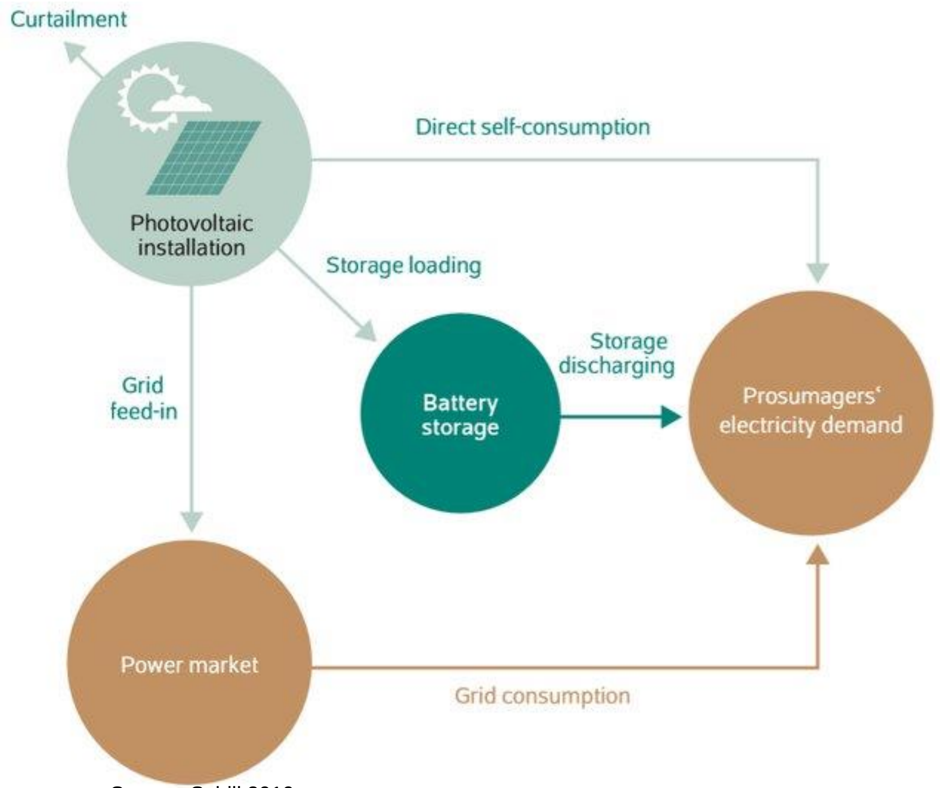
Introduction and research question

Prosumage

- Prosumage is growing in Germany
  - Current Netzentwicklungsplan (NEP) assumes an installed capacity of solar PV ranging from 400 GW until 445 GW in 2045 (NEP 2023, S.3)
  - Installed capacity of small scale batterie storage is assumed to be between 98 GW and 113 GW in 2045 (NEP 2023, S.39)
- Decision making of prosumers is not part of the wholesale market
  - Tariff designs determine investment and dispatch decision of prosumers
  - Raises the question of the effect of the decision of these prosumers on the transmission grid

How do different tariff designs influence the effects of solar prosumage on the transmission grid?

Solar prosumers:
Grid-connected residential electricity consumer who owns both a small-scale PV installation and a battery



Source: Schill 2019

Models

POMATO

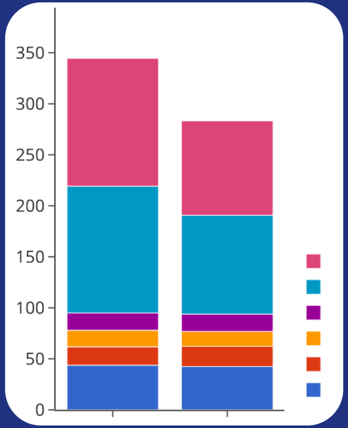
- POMATO (Power Market Tool) facilitates research on interconnected electricity markets within the context of the physical transmission system
- The electricity market model incorporates congestion management to minimize overall system costs
  - Supports various market types (zonal, nodal) and exchange mechanisms
  - Employs a DC load flow approach for modeling power flows
- Solves linear optimization problems

← Installed capacities

→ Dispatch (before & after redispatch)

→ Market prices

DIETER



- DIETER (Dispatch and Investment Evaluation Tool with Endogenous Renewables) is a comprehensive model for dispatch and investment decisions, encompassing various components
- The prosumage component calculates:
  - Investments by households in rooftop PV systems and home battery storage capacities
  - Prosumer dispatch decisions for optimal energy management
- Linear optimization problems

← Projected market prices

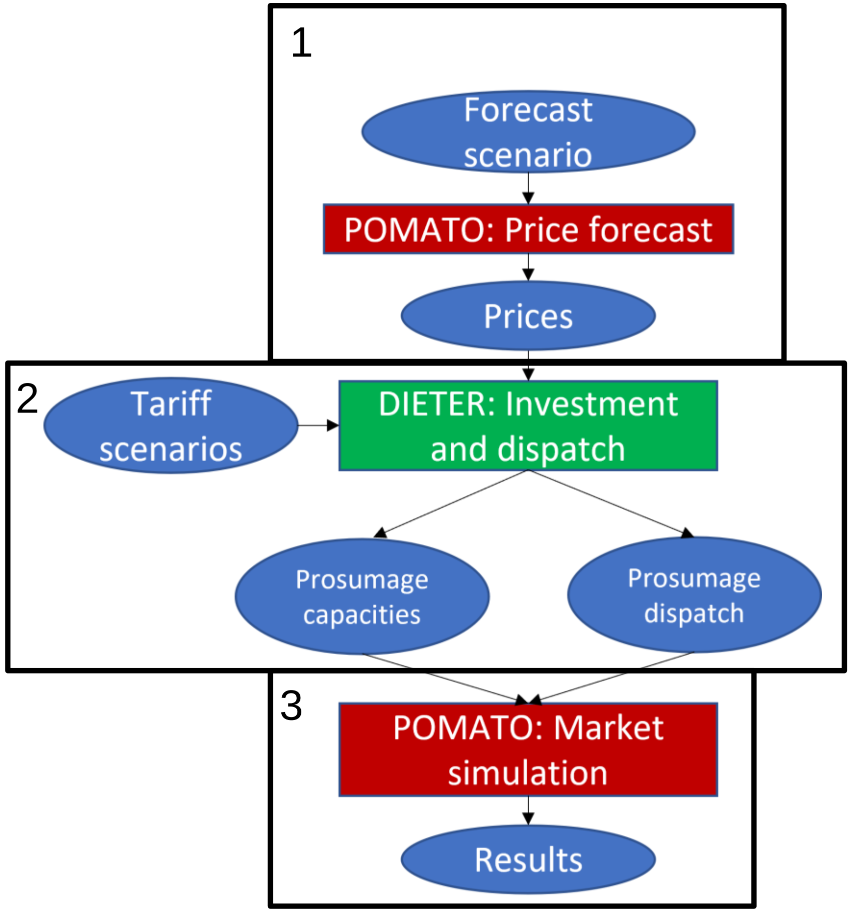
← Tariff design

→ Investment decision

Approach – Multi-stage framework

Multi-stage modeling framework

1. **Price forecast** (performed by POMATO)
   - Market prices serve as essential input for the investment model
   - Market simulation minimizes system costs
2. **Investment & dispatch decision** (by DIETER)
   - Households make decisions regarding investments in rooftop PV and home battery capacities
   - Households optimize the dispatch of their capacities to minimize electricity costs
   - Households are aggregated at transmission grid nodes
3. **Market simulation** (by POMATO)
   - Prosumagers' dispatch decisions are treated as fixed input
   - Market clearing, including congestion management, works to minimize system costs



Source: Own depiction

Approach – Tariff scenarios

- For each kilowatt-hour (kWh) that a prosumer contributes to the grid, they receive a payment of x cents as part of the feed-in tariff**.**
- Upfront payment to reduce variable cost component
- Real-time pricing is a dynamic pricing structure that varies based on current market conditions, while time-invariant pricing is a static pricing structure that remains constant.
- The market configuration is either one uniform German market (zonal), or a nodal approach with localized price signals.

Scenario	Feed-in tariff [ct/kWh]	Upfront payment [€]	Time depen-dency	Market type
FIX0_RTP_zonal	6	0	Real-time pricing (RTP)	zonal
FIX0_TIP_zonal	6	0	Time-invariant pricing (TIP)	zonal
FIX0_RTP_nodal	6	0	RTP	nodal
FIX0_TIP_nodal	6	0	TIP	nodal
FIX350_RTP_zonal	6	350	RTP	zonal
FIX350_TIP_zonal	6	350	TIP	zonal
FIX350_RTP_nodal	6	350	RTP	nodal
FIX350_TIP_nodal	6	350	TIP	nodal

Numerical experiment

- Analysis is based on scenarios inspired by Scenario C from Germany's grid development plan (NEP 2030) for the year 2030
- Installed capacities dominated by wind and solar energy
- Market simulations are conducted for one year, in hourly resolution, using either the current market design (uniform pricing + redispatch) or nodal pricing, depending on the scenario
- Over 600 transmission grid nodes from PyPSA
- High spatial resolution renewable time series (on the nodal level) are generated using atlite
- Regionalization of wind onshore and solar park based on extension potential
- Prosumage data is aggregated at the node level

Technology	Installed capacity [GW]
hard coal	8
lignite	9
gas	33.3
other conventionals	5
biomass	8.5
hydro	10.4
wind onshore	85.5
wind offshore	18.3
solar park	31.2
rooftop solar	endogenous
home battery	endogenous

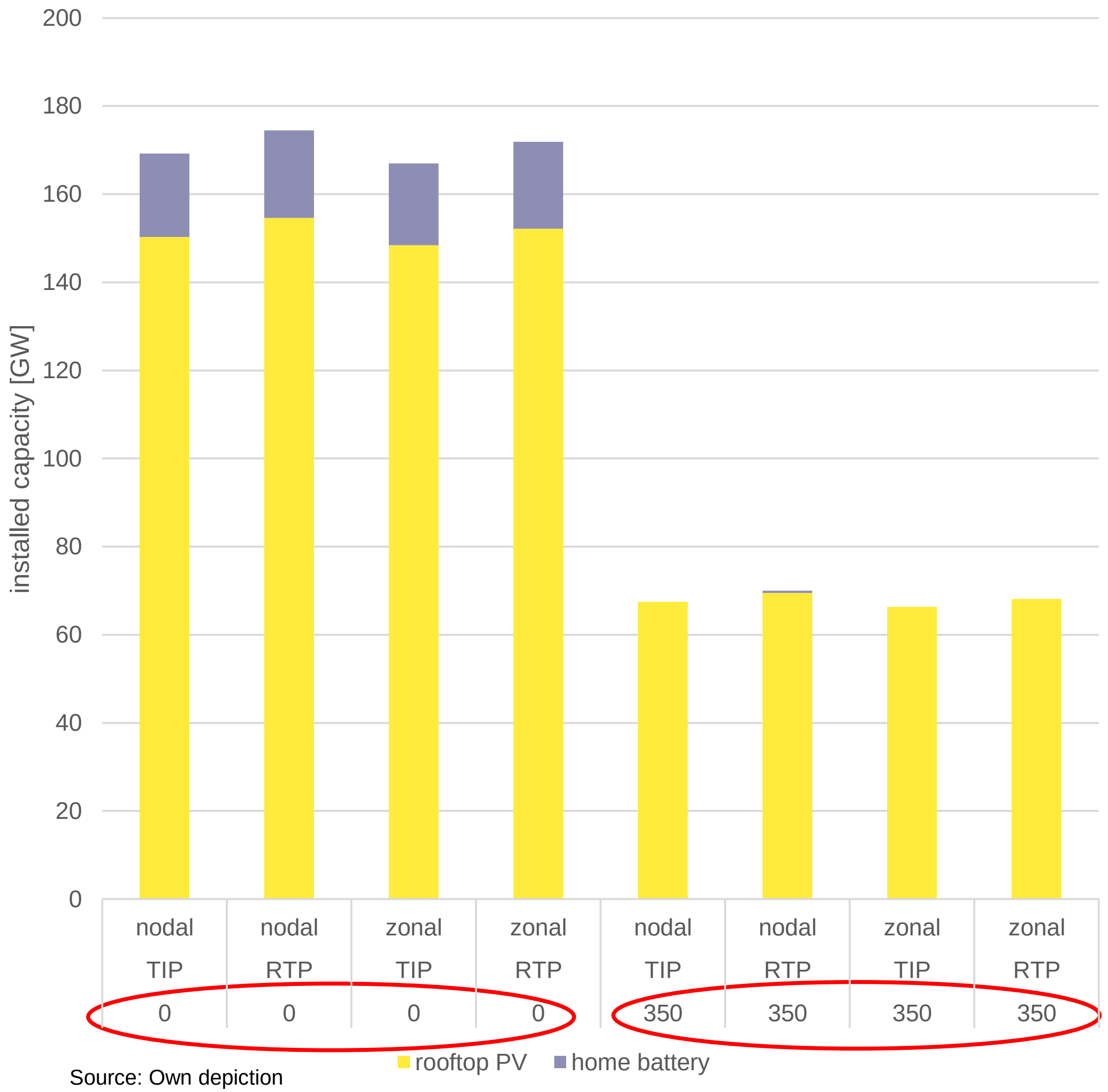
Source: NEP 2030

Source: Own depiction generated with mapbox

Sources: BNetzA 2018, Hörsch 2018, Hofmann 2021, Ebner 2019

Results - Investments

- Upfront non-energy payment
  - ➢ Has a significant impact on solar PV investments
  - ➢ High payment leads to almost no investments in batteries



Source: Own depiction

Results - Investments

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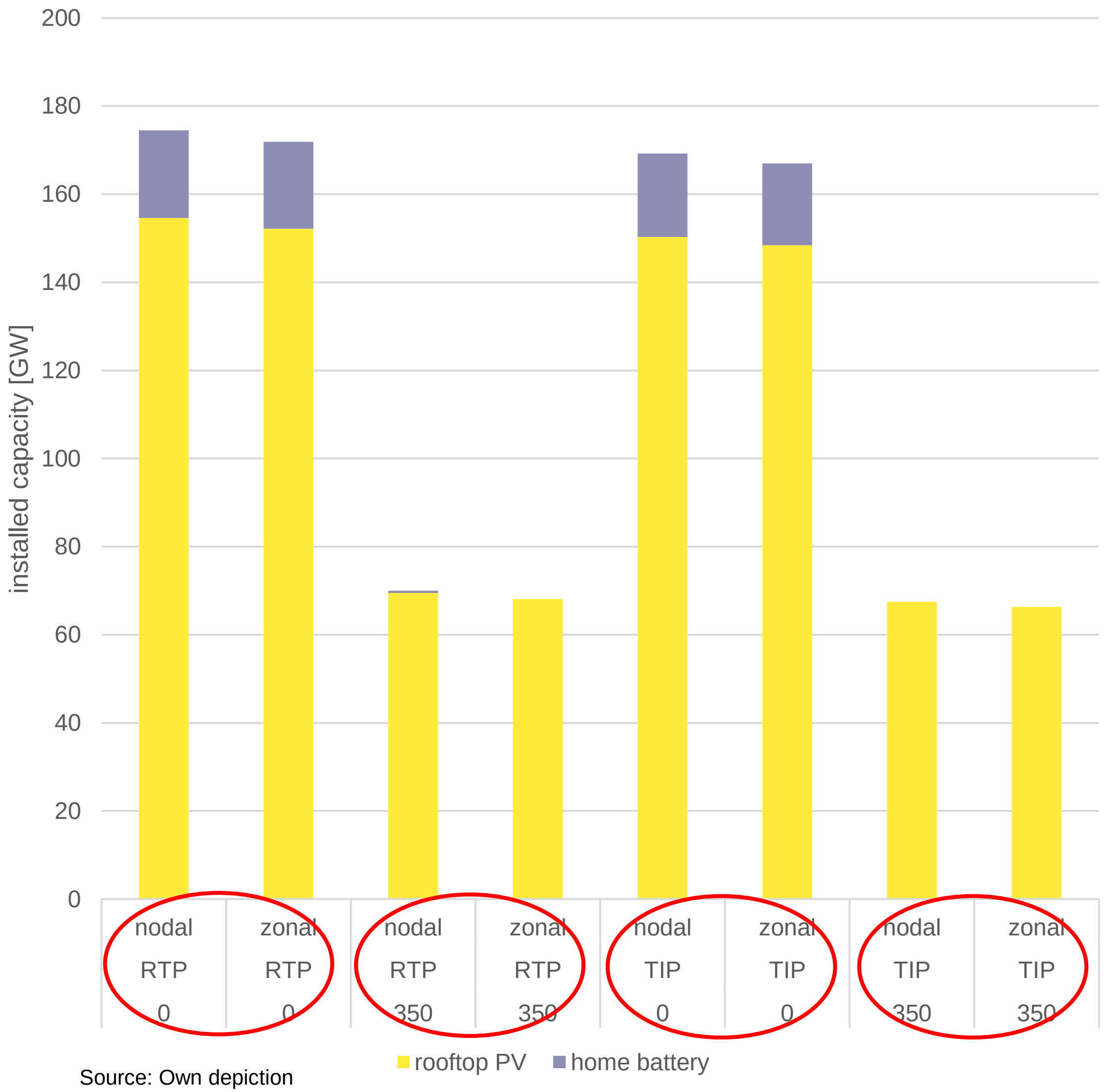
- The configuration of the market (nodal vs. zonal)
  - ➢ has small impact on prosumer investments
  - ➢ nodal pricing seems to incentives a bit more PV investments



Source: Own depiction

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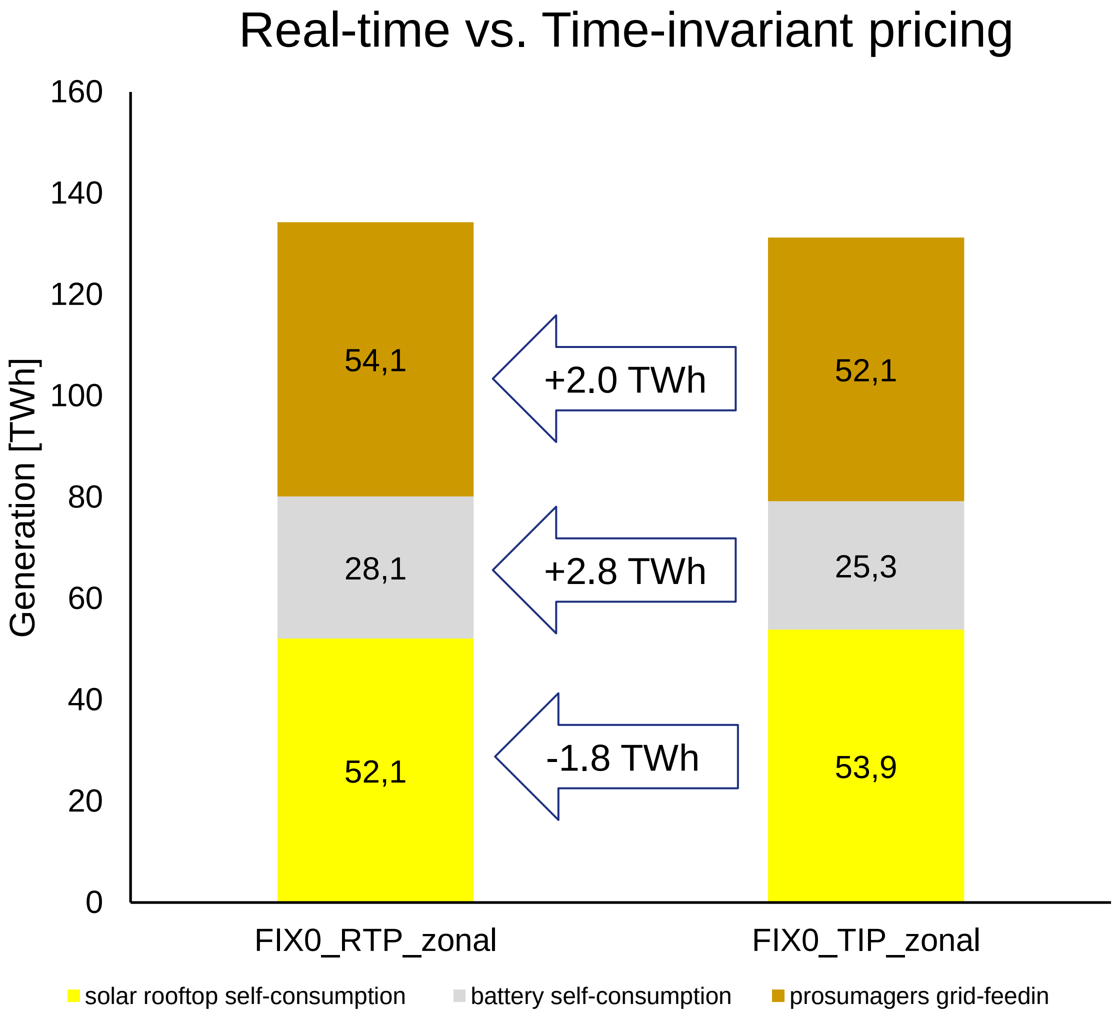
- Pricing scheme (real-time vs. Time-invariant)
  - ➢ impact is also relative small
  - ➢ RTP incentives slightly higher investments into solar PV and battery storages

Source: Own depiction

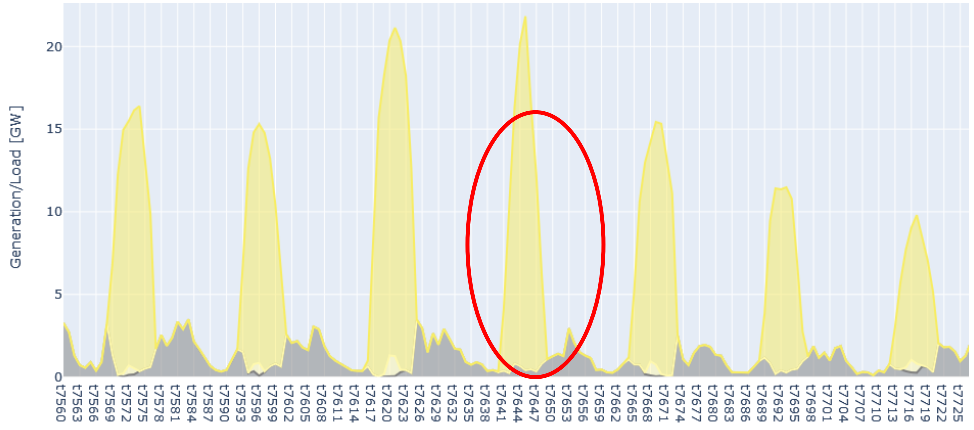
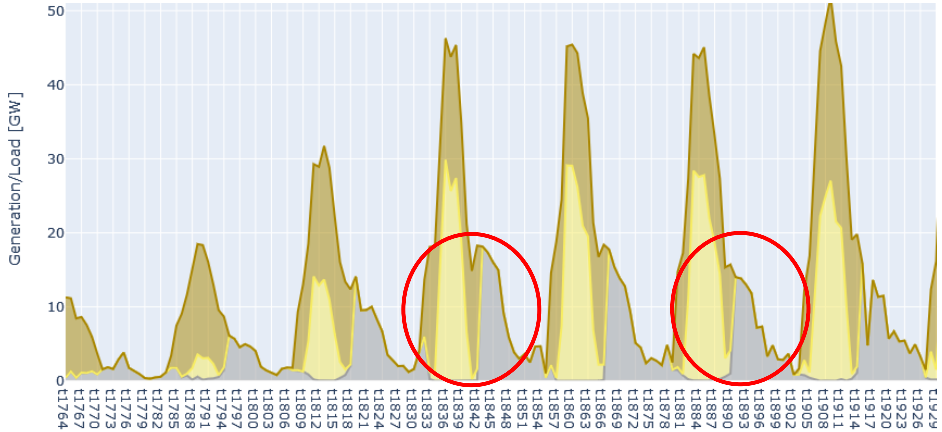
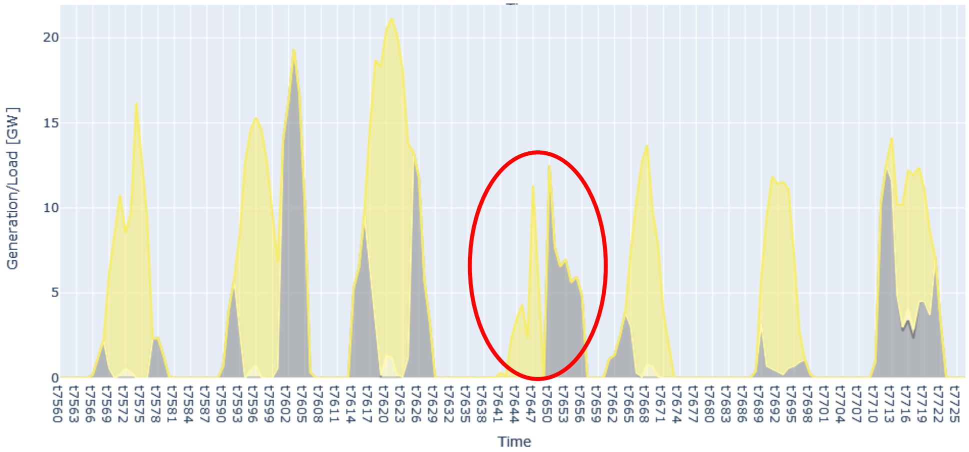
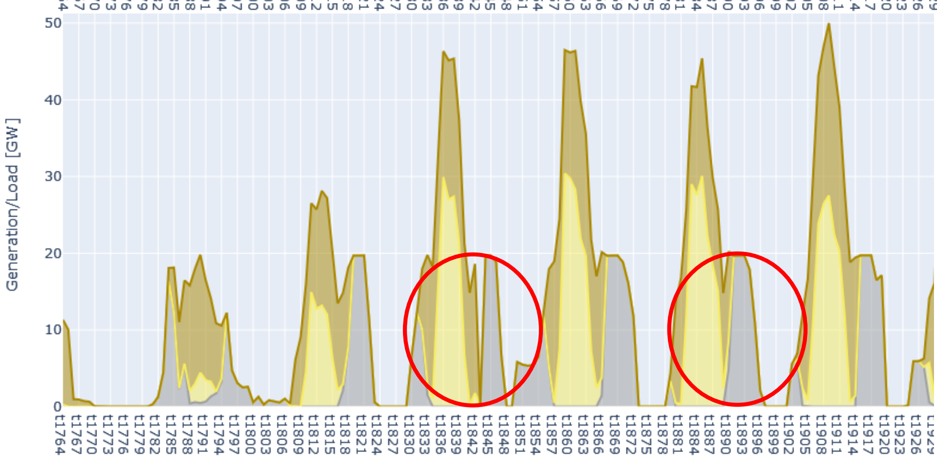
Results - Dispatch

- Real-time pricing leads to an increase in battery storage usage
- A slight shift is observed from self-consumption towards feeding electricity into the grid
- However, these effects are relatively small, and the results should be considered tentative



Source: Own depictions

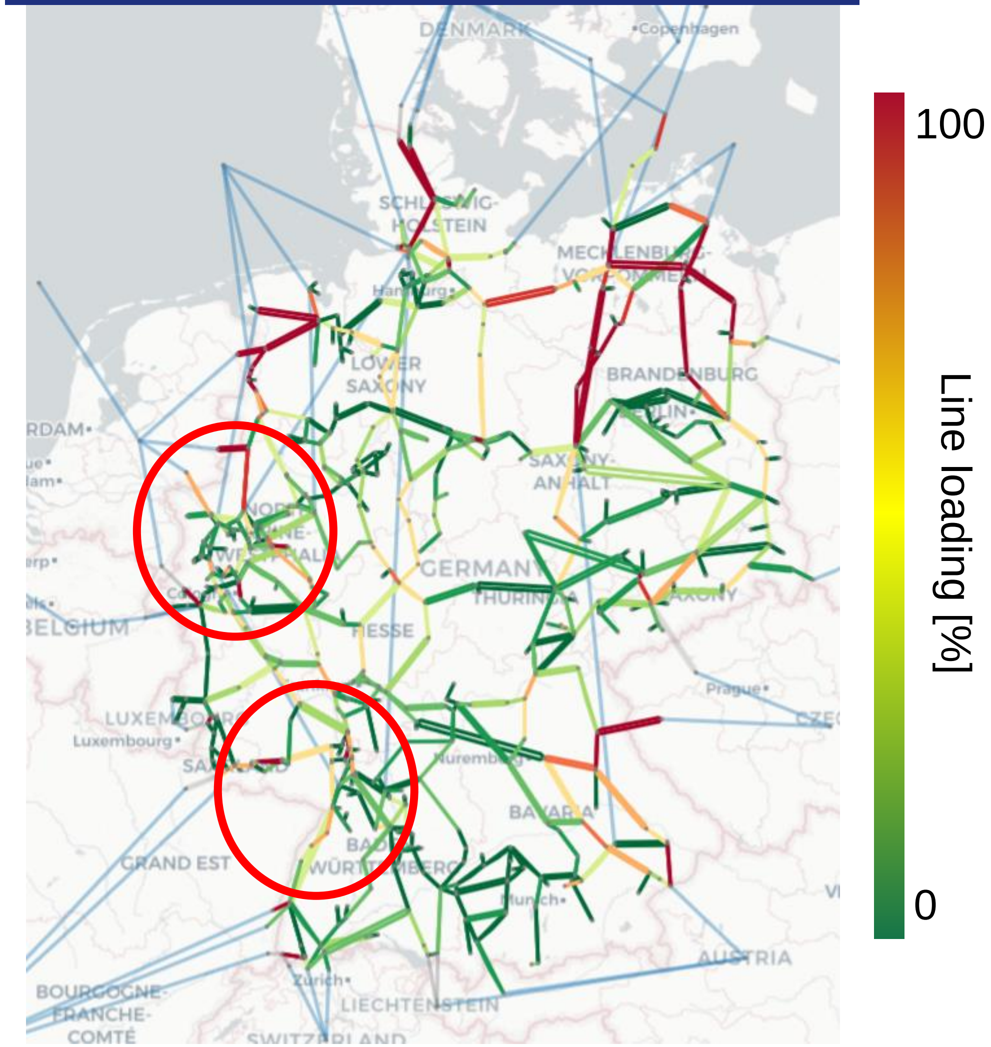
Results – Dispatch example

	Week in November	Week in March
Time-invariant		
Real-time		

Battery self-consumption   Prosumagers grid feedin   Solar rooftop self-consumption

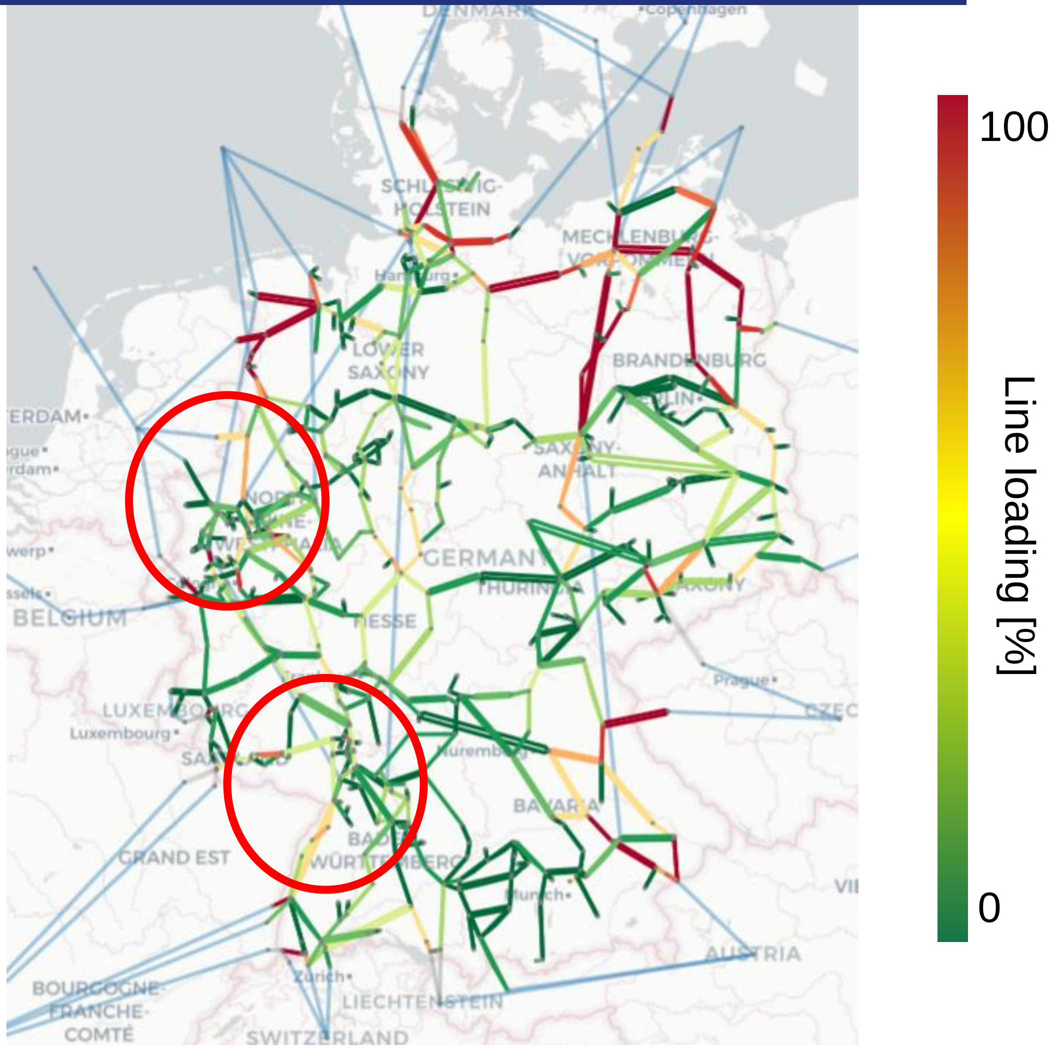
Results – Snapshot of the grid in March

Real-time



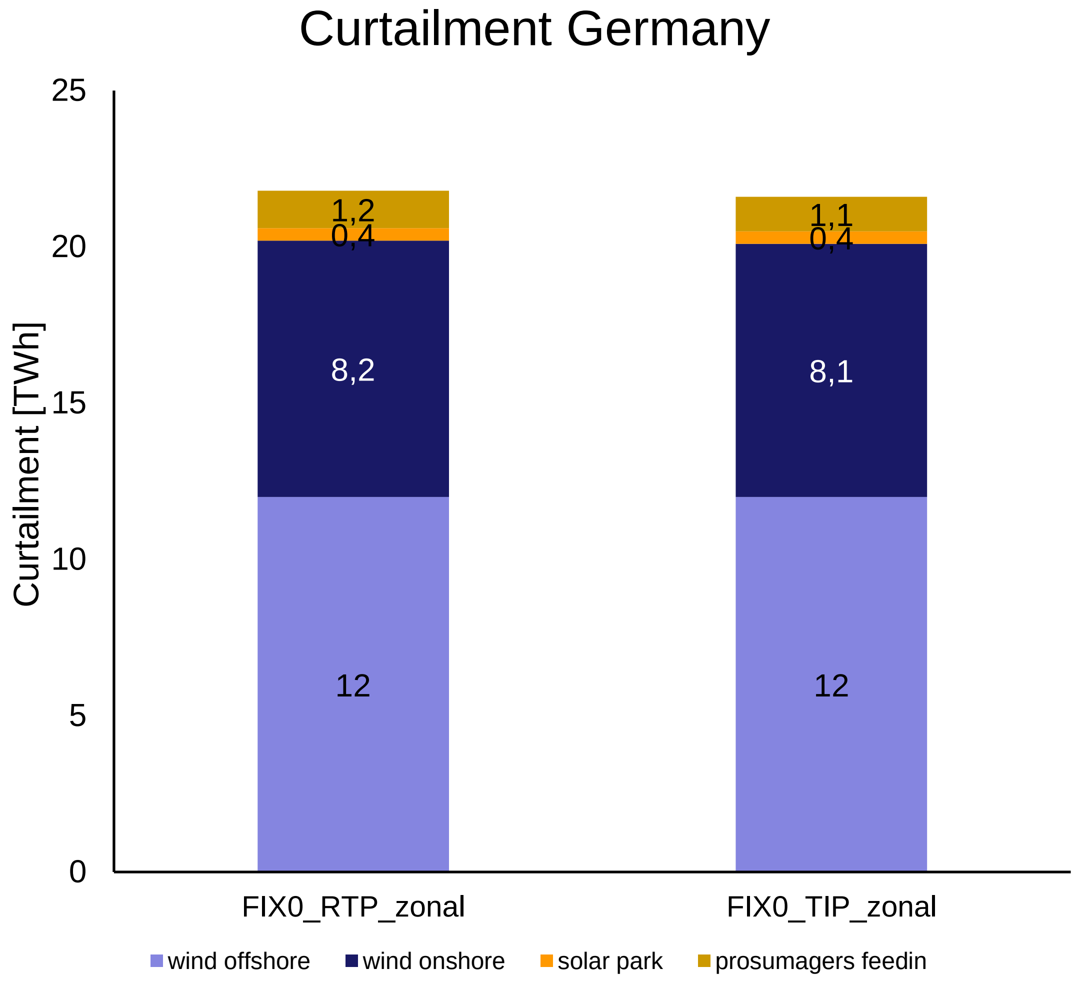
Source: Own depiction generated with mapbox

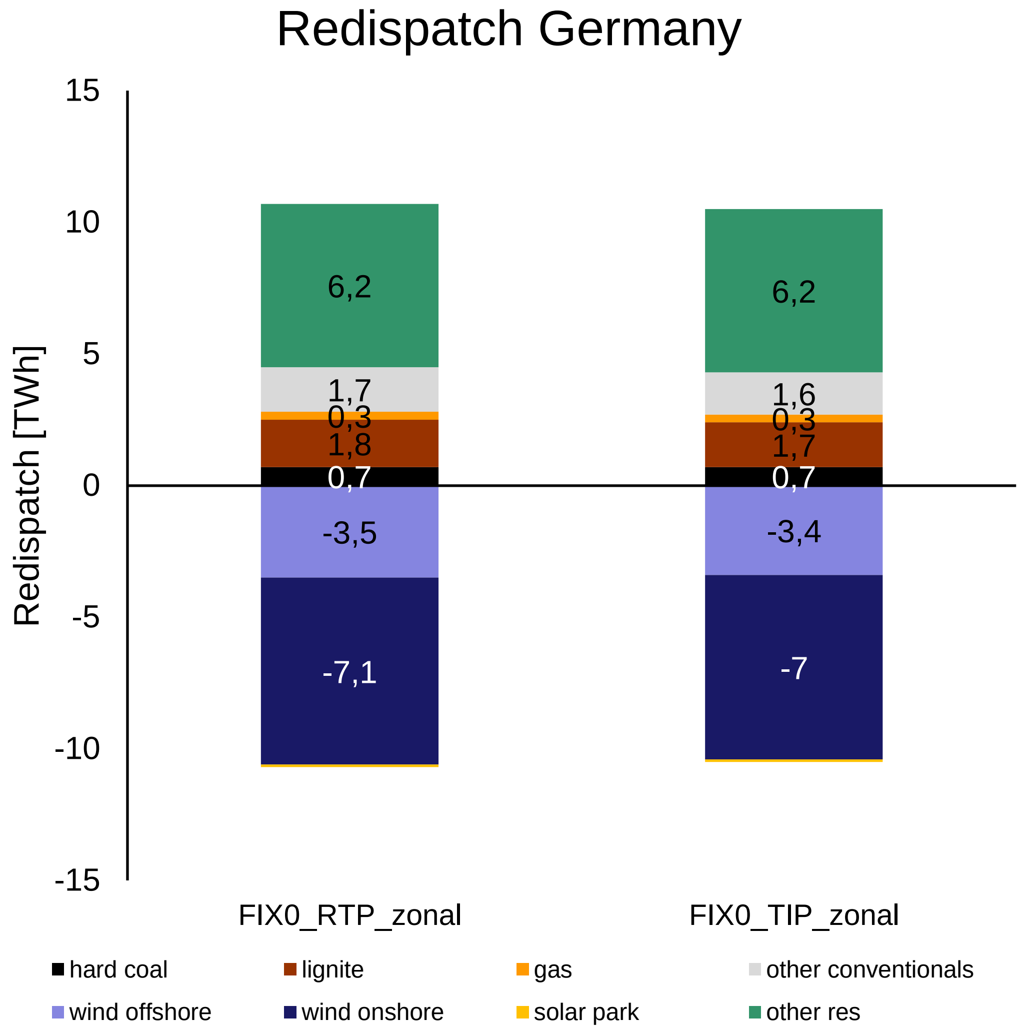
Time-invariant



Source: Own depiction generated with mapbox

Results – Curtailment and Redispatch



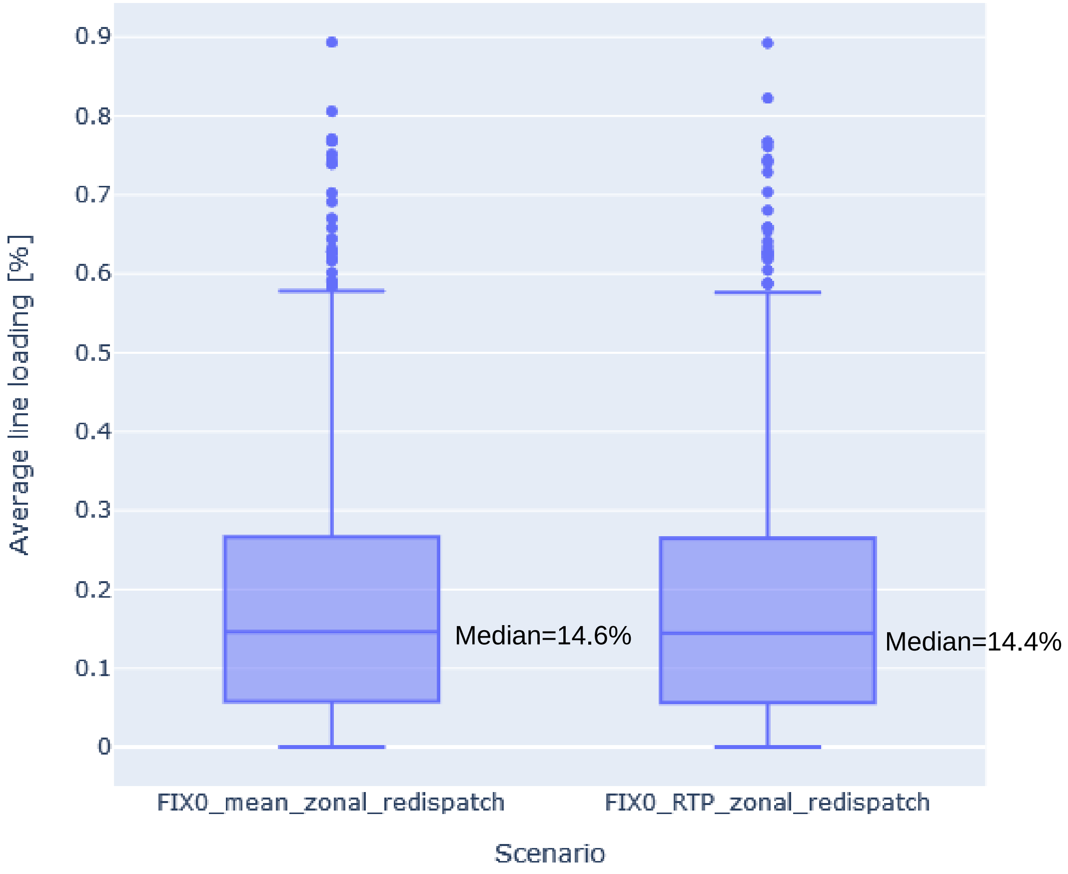


Source: Own depiction

Results - Grid

- No significant differences in network utilization, on average and during peak hours, are found between scenarios with RTP and TIP
- Changes between scenarios primarily occur during individual hours
- As a result, curtailment and redispatch remain largely unaffected by the temporal pricing component

Average loading of
German transmission lines



Source: Own depiction

Discussion

Preliminary Results:

- The temporal dimension of retail prices (RTP vs. TIP) has a minor impact on the total system
- The market configuration (Zonal vs. Nodal pricing) also exhibits a small influence
- Fixed feed-in tariffs, variable non-energy costs, and PV availability are the primary factors driving prosumer behavior

Modelling challenges:

- Linking wholesale market price with the effects of dispatch decisions by prosumers: Wholesale market prices are necessary for prosumers to make their dispatch decisions, but these decisions, in turn, influence the market prices
- Placing assumed newbuilt capacities has an impact on the transmission grid

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Thank you for your attention!

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