House of Energy Markets & Finance

Prosumers with PV battery systems in electricity markets – a mixed complementarity approach

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MODE ZEEN

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Introduction

- Which adjustments to the regulatory framework can work towards a **system-oriented operation** of decentralized flexibilities?
- Considering decentralized actors, we **focus on prosumers**.
- We **discuss the role of retailers**.
- We use the concept of **Mixed Complementarity Problems** (MCP)
  - Different optimization problems are combined in one equilibrium model

Motivation

Research on residential PV battery systems

Sector coupling

- Decentralized sector coupling and flexibility options are important for the integration of renewable energies.

  → e.g. Bernath et al. (2021), Fridgen et al. (2020)

Investments in PV battery systems

- Increased investments in PV battery systems are accompanied by higher availability of decentralized flexibility.

  → e.g. Dietrich, Weber (2018), Kappner et al. (2019)

Increasing self-consumption

- Current regulatory design incentivizes self-consumption.

  → e.g. Bertsch et al. (2017)

System-oriented in this context: Provide more Flexibility / system-oriented use of decentralized flexibilities.

Focus on incentives for system-oriented investments

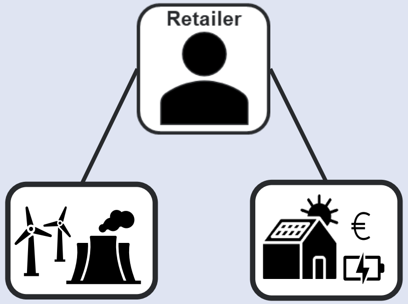
- **Dietrich & Weber (2018)**
  - **Focus:** Profitability of residential PV battery storage system
  - **Method:** Mixed-integer linear optimization model
  - **Highlights:** High temporal resolution (5 Minutes)
    Accounting for regulatory and fiscal treatment of prosumers

- **Günther et al. (2021)**
  - **Focus:** Tariff design incentives on household-investments in residential PV and battery storage systems
  - **Method:** MCP
  - **Highlights:** Considers prosumage-household and wholesale-market
    lower feed-in tariffs reduce PV-Investments

Research Gap

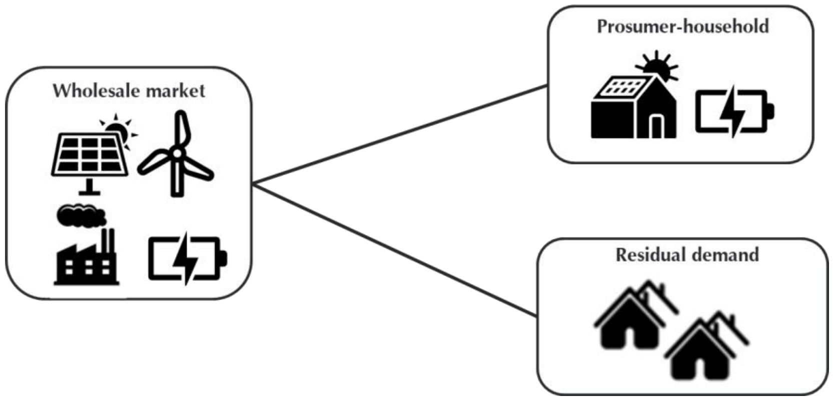
- Role of Retailer and system feedback effects
- Incentives for **system-oriented investments** in residential PV and battery storage systems

➢ MCP-Modelling: Consideration of multiple optimization problems in one equilibrium model

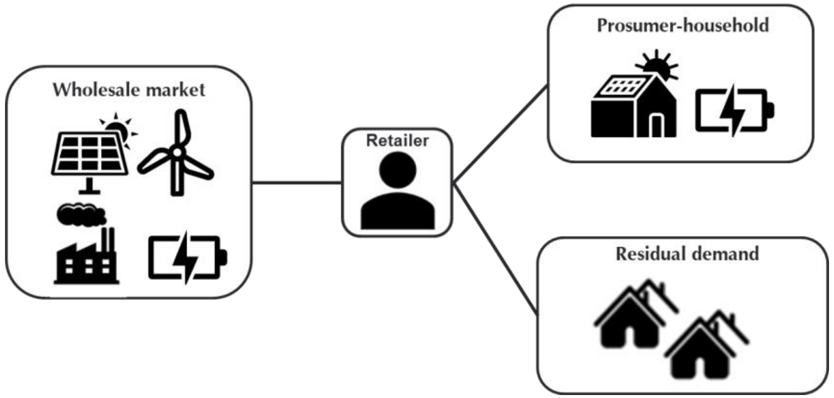


- **Framework 1**
  - Wholesalemarket and Prosumer-household
    - Dynamic retail prices based on hourly market clearing
- **Framework 2**
  - Wholesalemarket, **Retailer** and Prosumer-household
    - retail tariff as retailer's decision variable
    - s. t. profit restriction

Framework 1



Framework 2



$$Min! \overbrace{\sum_{t,i}\left(C_{i,t}^{op} * q_{i,t}^{prod}\right)}^{\text{Operating Costs}} + \overbrace{\sum_{t}\left(C_{t}^{curt} * q_{t}^{who\_curt}\right)}^{\text{Curtailment Costs}}$$

Important assumptions:

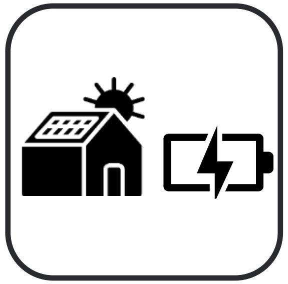
- Power plant portfolio
  - Conventionals
  - Renewables
  - Storages
- No (dis-)investments
- Perfect foresight, all actors are price takers
  - No rolling planning appraoch

Modelling:

- Minimize system costs
- Constraints
  - Market clearing
  - Capacity restrictions
  - Storage filling level

Prosumer

Model details



$$Min! \sum_t \overbrace{p_t^{who} * q_{h,t}^{gridout}}^{\text{Grid-consumption}} + \overbrace{\tau * \frac{p_t^{who}}{1+\tau}\left(\left(K_h^{PV} + k_h^{PV}\right) * \varphi_{i,t} - q_{h,t}^{curt} - q_{h,t}^{gridin}\right)}^{\text{Self-consumption}} - \overbrace{P^{fit} * q_{h,t}^{gridin}}^{\text{Feed-in}} * \Delta t$$

$$\underbrace{+ C^{invPV} * k_h^{pv} + C^{invBatV} * v_h^{bat} + C^{invBatK} * k_h^{bat}}_{\text{Investments}}$$

Important assumptions:

- Investments in PV and battery storages
- Self-consumption
- Grid-consumption
- Feed-in tariff
- Storage usage

Modelling:

- Minimize system costs
- Constraints
  - Demand balance (market clearing)
  - Feed-in restriction
  - Capacity restrictions
  - Storage filling level
  - Investment restrictions (capacity limits)

Retailer

Model details

$$Max! \sum_{h,t} \underbrace{(q_{h,t}^{gridout} + Q_t^{res}) * p^{ret}}_{\text{Retail Tariff}} - \sum_{h,t} \underbrace{(q_{h,t}^{gridout} + Q_t^{res}) * p_t^{who}}_{\text{Wholesale prices}}$$

Important assumptions:

- No market power vs. market power
- No intermediate storage
- Sole link between prosumer and wholesale market
  - Purchases at **time-dependent** price on wholesale market
  - Sells at **time-independent** price to consumers

Modelling:

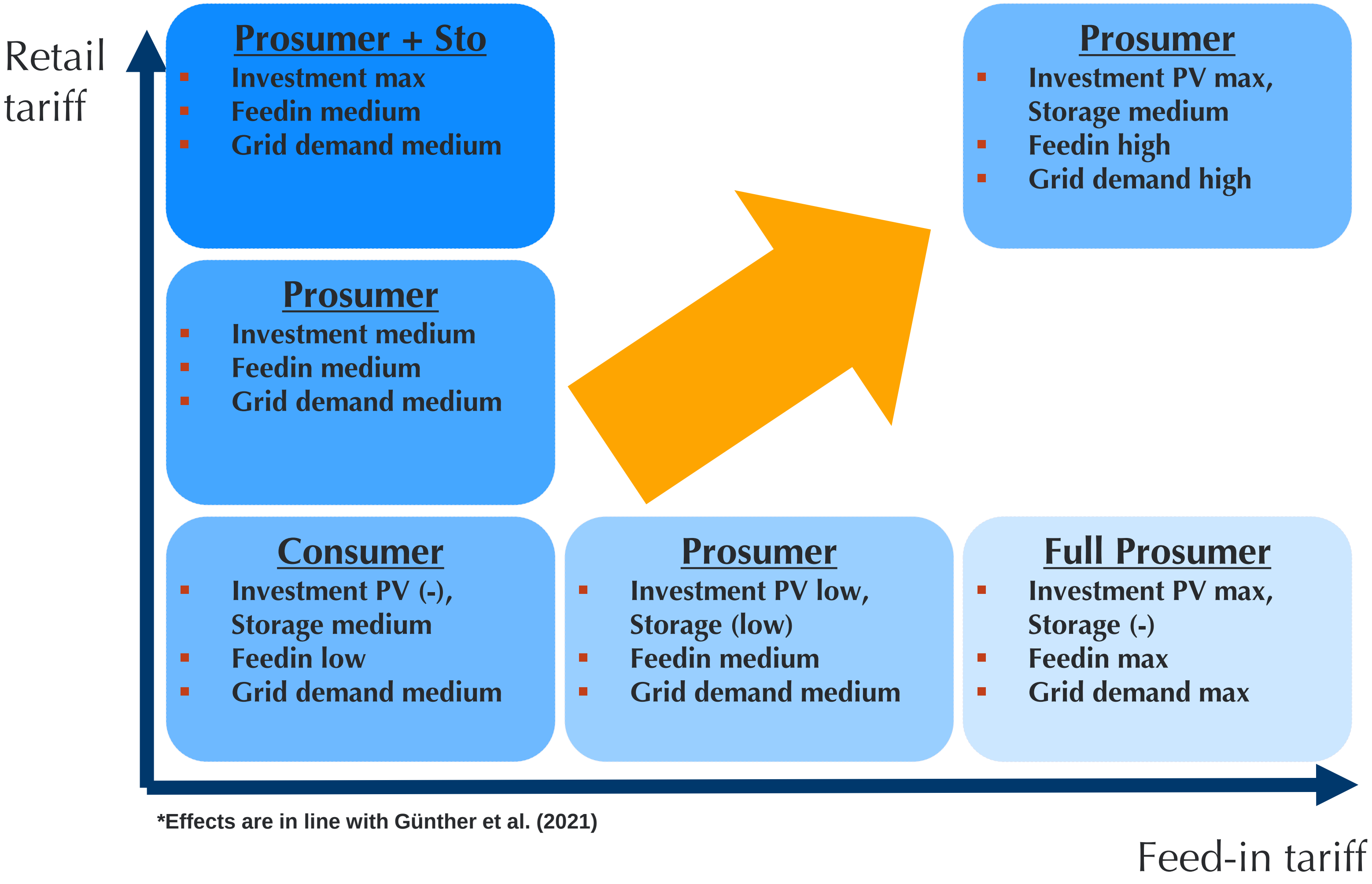
- Maximize profit
- Constraints
  - Retailer yearly Profit greater than zero

Preliminary results (simplified setting)

24 Timesteps

Assumptions:

- 24 timesteps
  - hourly resolution
- Endogeneous household-investments
  - PV
  - Battery Storage
- Variation of tariffs
  - Retail tariff
  - Feed-in tariff



Self-consumption level

low high

*Effects are in line with Günther et al. (2021)

Next Steps

Outlook

- Model scaling
  - Full year (hourly resolution)
  - Geographical Scope (Germany, EU)
  - Prosumer Profiles (Open Power System Data)
  - Wholesale market (TYNDP, Netzentwicklungsplan* (NEP))
- Case Studies
  - Retail tariff design
    - Real time pricing
    - Static pricing
    - weighted pricing
  - Regulatory framework
    - Taxes and levies
    - Subsidies
      - e.g. investment or operation
  - Different energy systems
    - Power plant portfolio
    - Renewables
    - Flexibilities

→ role of retailer

→ incentives for system-oriented investments

→ system feedback effects

* **Bundesnetzagentur (BNetzA): Grid Development Plan for German energy system**

Thank you for your attention!

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