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

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MODEZEEN

UNIVERSITÄT DUISBURG ESSEN

Offen im Denken

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

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)

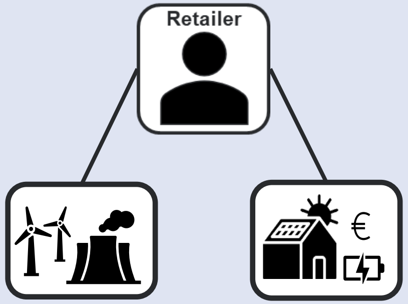
Focus on incentives for system-oriented investments

- **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

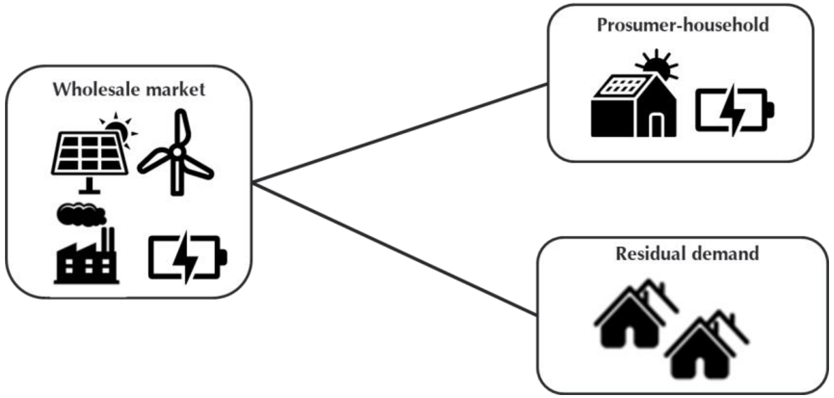
- Role of Retailer and system feedback effects
- Incentives for **system-oriented investments** in residential PV and battery storage systems
- ➢ MCP-Modelling: Consideration of multiple optimization problems in one equilibrium model



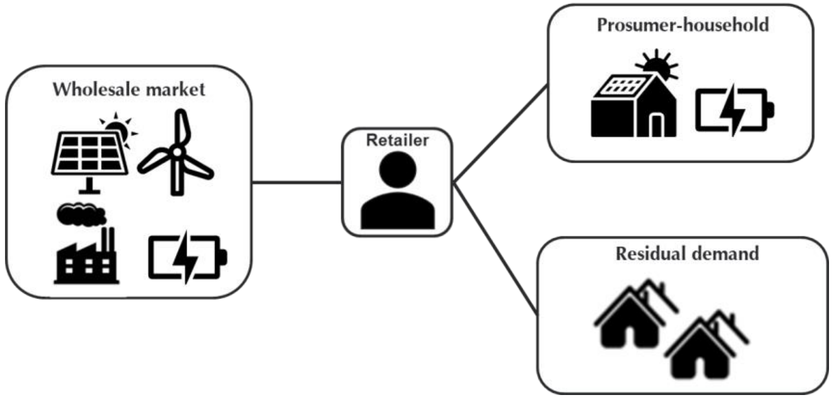
Model framework (2-step approach)

- **Framework 1**
  - Wholesalemarket and Prosumer-household
    - Dynamic retail prices based on hourly market clearing
    - Static retail price based on average market clearing
- **Framework 2**
  - Wholesalemarket, Retailer and Prosumer-household
    - Dynamic retail prices based on hourly market clearing incl. retailer margin
    - Static retail price based on average market clearing incl. retailer margin
    - Weighted retail tariff

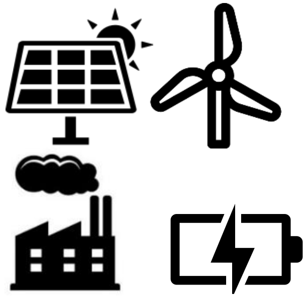
Framework 1



Framework 2



Wholesale market



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

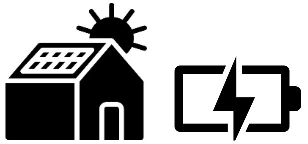
Important assumptions:

- Power plant portfolio
  - Conventionals
  - Renewables
  - Storages
- No (des-)investments
- Minimize system costs
- Constraints
  - Market clearing
  - Capacity restrictions
  - Storage filling level
- Perfect foresight, all actors are price takers

Prosumer-household

Model details

Prosumer-household



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

$$\underbrace{-P^{fit} * q_{h,t}^{gridin} * \Delta t}_{\text{Grid feed-in}} + \underbrace{C^{invPV} * k_h^{pv} + C^{invBatV} * v_h^{bat} + C^{invBatK} * k_h^{bat}}_{\text{Investments}}$$

Important assumptions:

- Minimize (system) costs considering
  - Investments in PV and battery storages
  - Self-consumption
  - Grid consumption
  - Feed-in tariff
  - Storage usage
- Constraints
  - Demand balance (market clearing)
  - Feed-in restriction
  - Capacity restrictions
  - Storage filling level
  - Investment restrictions (capacity limits)

Retailer

Model details

$$Max! \sum_{h,t} p^{pro}_{h,t} \cdot q^{gridout}_{h,t} + \sum_{t} p^{con} \cdot Q^{res}_{t} - \sum_{t} p^{who}_{t} \cdot q^{who}_{t}$$

Price for prosumer

Possible variant

Weighted Mix of yearly average wholesale price and time dependent wholesale price (incl. retailer margin)

Price for residual households

Average wholesale price (incl. retailer margin)

Important assumptions:

- Maximize profit
- 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 (in case of static retail tariff)
    - Further assumptions
      - RTP
      - (weighted) mix-up

Case study setting

Different standardized energy systems regarding

- Power plant portfolio
- Renewables
- Flexibilities

Retail tariff design

- Real time pricing
- Static pricing
- weighted pricing

Regulatory framework

- Levies and taxes
- Subsidies
  - Investment
  - Operative
    - e.g. different feed-in tariff designs

Identification of (regulatory) designs that lead to a **system-oriented use of decentralized flexibilities.**

Thank you for your attention!

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