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

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MODEZEEN

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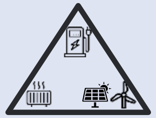
Introduction

- 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

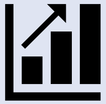
- Decentralized sector coupling and flexibility options are important for the integration of renewable energies.

  → 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)

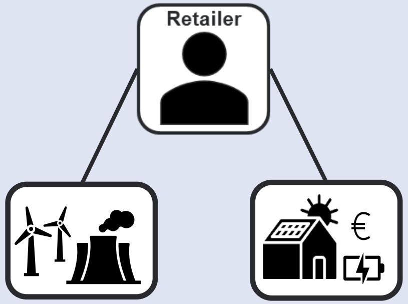
Focus on incentives for system-oriented investments

- **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



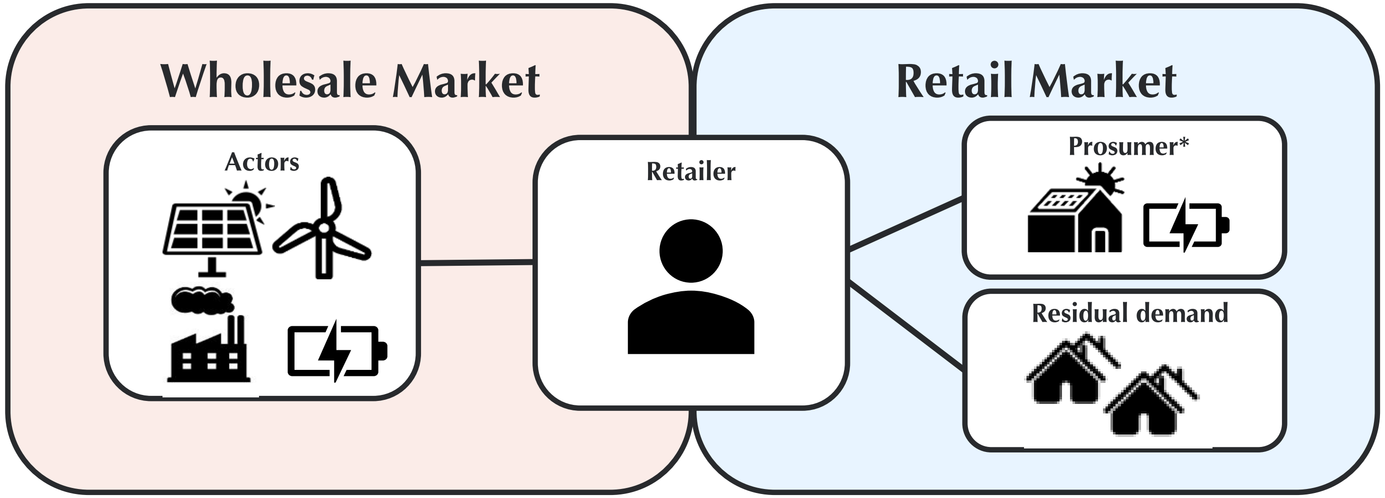
Model framework

Wholesale Market

- Actors:
  - Conventionals power plants
  - Storage operator
- Global market clearing condition

Retail Market

- Actors
  - Retailer
  - Prosumer*
- Global market clearing condition



* We refer to Prosumer as a household, which produces and consumes electricity (PV-System).
We further refer to Prosumage-households as households, which are able to store the produced electricity (battery storage)

$$\overbrace{q_{i,t}^{prod}}^{\text{Conventional power plants}} + \underbrace{s_{j,t}^{-} - s_{j,t}^{+}}_{\text{Storage operator}} + \overbrace{Q_t^{EE}}^{\text{(so far) Exogeneous renewables}} \geq \underbrace{q_t^{ret}}_{\text{Demand of retailer}} \; \forall\, i, j, t \; (p_t^{who})$$

Important assumptions:

- Actors
  - Conventional power plants
  - Storage operator
  - (Renewables supply is exogenously given)
- No (Dis-)Investments
- Perfect foresight, all actors are price takers
  - No rolling planning approach

Global condition:

- Global market clearing condition
  - All (producing) actors must supply at least the energy demanded by the retailer
- Dual variable as wholesale price

Wholesale Market Actors: Conventional Power Plants

Model details

Important assumptions:

- Conventional power plants
  - Profit maximization
  - Price taker
  - Restricted by
    - Capacity constraint
- No (dis-)investments

Wholesale Market

Wholesale Market Price; Production; Operational Costs

$$Max! \sum_t \left(p_t^{who} - C_{i,t}^{op}\right) * q_{i,t}^{prod}$$

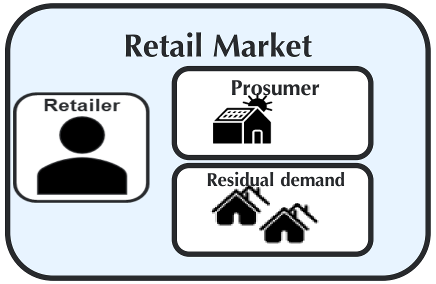
Important assumptions:

- Storage operator
  - Profit maximization
  - Price taker
  - Restricted by
    - Filling level constraints
    - (Dis-)Charging capacity constraints
- No (dis-)investments

$$Max! \sum_t \overbrace{p_t^{who}}^{\text{Wholesale Market Price}} * \underbrace{\left(s_{j,t}^- - s_{j,t}^+\right)}_{\text{(Dis-)Charging}}$$

Retail Market

Model details



Demand of Retailer on Wholesale Market — Demand from Prosumer

$$q_t^{ret} + q_{h,t}^{gridin} \geq q_{h,t}^{gridout} + Q_t^{res} \forall i,j,t \; (p_t^{ret})$$

Infeed from Prosumer — Demand of Residual Households

Important assumptions:

- Actors
  - Retailer
  - Prosumers
  - (Residual households′ demand is exogeneously given)
- Investments into PV and battery storage
- All actors are price takers

Global condition:

- Global market clearing condition
  - Retailer must supply at least the energy demanded by the prosumers and residual households
  - Infeed by prosumers is considered
- Dual variable as retail price

Retail Market Actors: Retailer

Model details

Important assumptions:

- Retailer
  - Profit maximization
  - Price taker

Wholesale Market Price and Quantity

$$Max! \sum_t q_t^{ret} * \left(p_t^{ret} - p_t^{who}\right)$$

Retail Market Price and Quantity

Model details

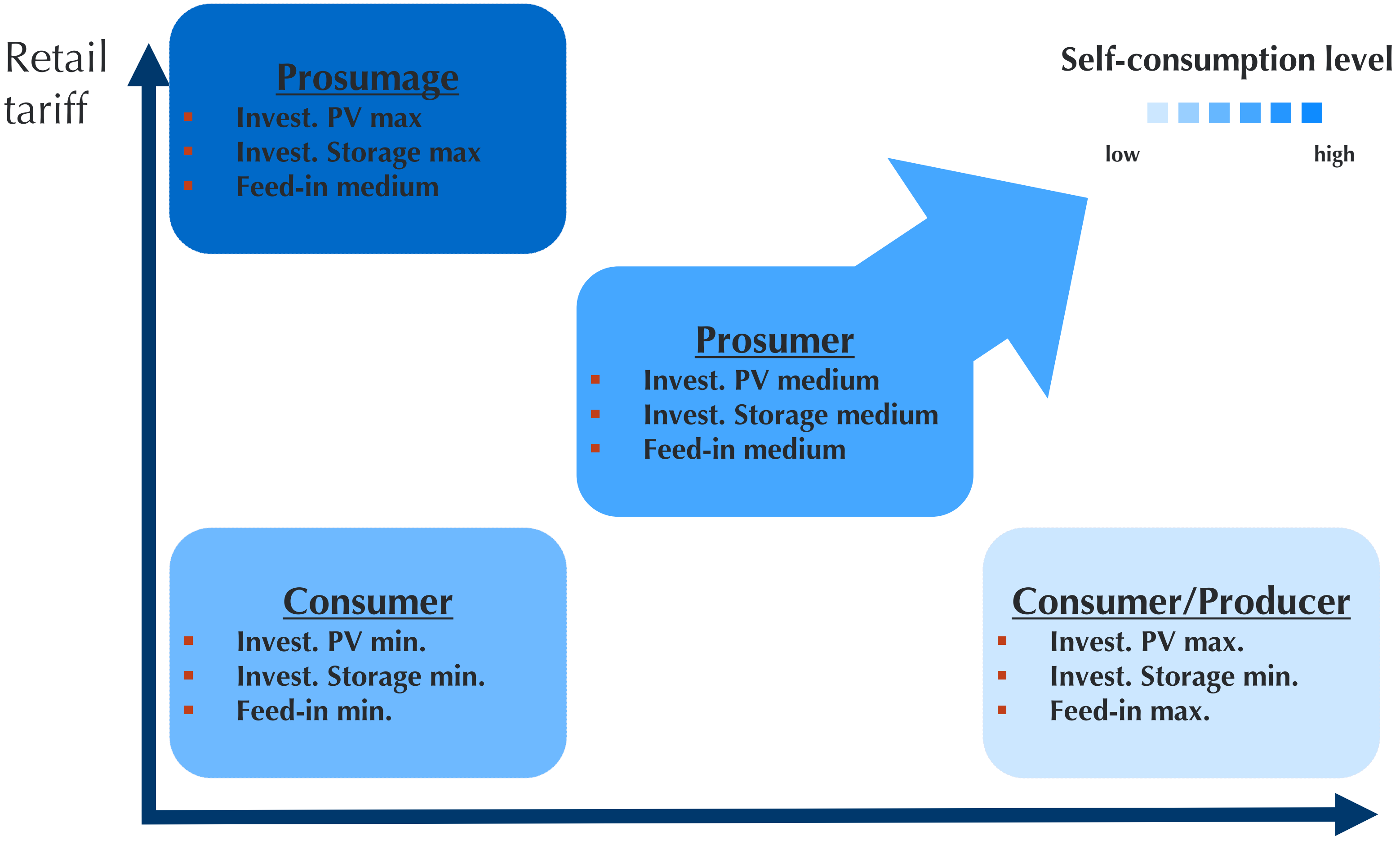
Important assumptions:

- Prosumer
  - Profit maximization
  - Price taker
  - Restricted by
    - Demand balance
    - Feed-in restriction
    - Capacity restrictions
    - Storage filling level
    - Investment restrictions (capacity limits)
- Investments into PV and battery storage

$$Max! \sum_t \underbrace{p^{fit} * q^{gridin}_{h,t}}_{\text{Infeed}} - \underbrace{p^{ret}_t * q^{gridout}_{h,t}}_{\text{Quantity purchased from Retailer}} \underbrace{- \tau * \frac{p^{ret}_t}{1+\tau}\left(\left(K^{PV}_h + k^{PV}_h\right) * \varphi_{i,t} - q^{gridin}_{h,t}\right)}_{\text{Self-Consumption}} \underbrace{- C^{invPV} * k^{pv}_h - C^{invBatV} * v^{bat}_h - C^{invBatK} * k^{bat}_h}_{\text{Investment in PV or Storage}}$$

Simplified setting:

- Retailer without market power
- Endogenous household-investments
  - PV
  - Battery storage
- Variation of tariffs
  - Retail tariff
  - Feed-in tariff



Results are in line with Günther et al. (2021)

Model scaling

- Full year (hourly resolution)
- Geographical Scope (Germany, EU)
- Prosumer Profiles (Open Power System Data)
- Wholesale market (TYNDP)

Case studies

- Retail tariff design
- Regulatory framework
- Different energy systems

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Thank you for your attention!

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