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HOCHSCHULE LANDSHUT

Optimal and Almost Optimal Strategies for Rational Agents in a Smart Grid

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Presenter Introduction

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Alexander Wallis, M.Sc.

- *since 2018:* Research Assistant of Prof. Sascha Hauke Research: Machine Learning for Smart Grids.
- *2016-2018:* Software Developer for BMW Group and MENTZ GmbH.
- *2008-2016:* B.Sc and M.Sc. in Computer Science at UAS Landshut.

University of Applied Sciences Landshut

Motivation

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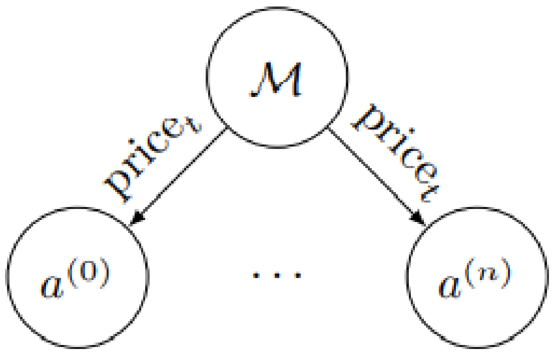
- Electrical grids are evolving from **centrally managed** critical infrastructure to **distributedly managed** Smart Grids.
- Also the **consumer** within a power grid is evolving to so-called ***prosumers***:

- **Problem:** More uncertainty is added into the power grid.
  ➡ To handle this, the interaction between **independent rational actors** needs to be studied.
- **Approach:** This falls within the domain of **Game Theory** (GT).

The Game

- We propose a **game *G*** to analyze the interactions between **prosumers** and an **electricity market *M***.
  - **Prosumers:** set of rational **agents *A***.
  - **Electricity Market:** provide price per kWh for **buying** and **selling** electricity.



- In every time interval *t* the market sends the price to all agents within the game.

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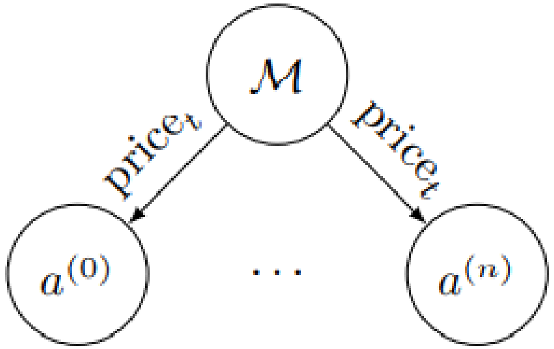
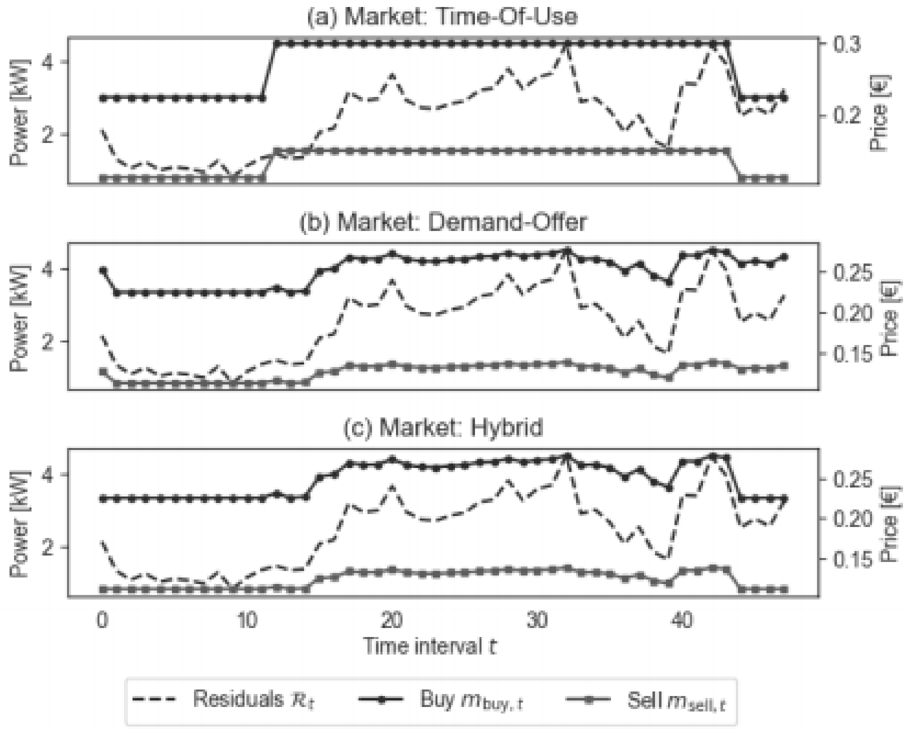


- In every time interval *t* the market sends the price to all agents within the game.
- Possible market structures: **Time-Of-Use**, **Demand-Offer and Hybrid**.



Prosumers as Rational Agents

- In our game, prosumers are represented as **rational agents**.
- We categorize the agents based on available **production**, **consumption** and **storage** capacities:

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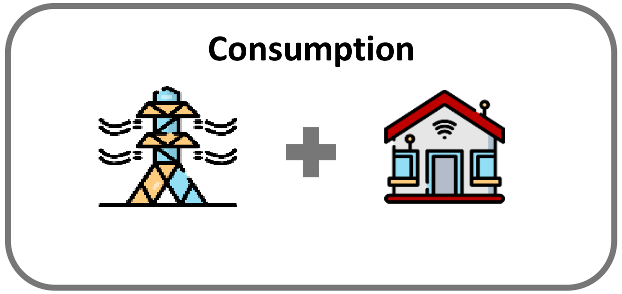

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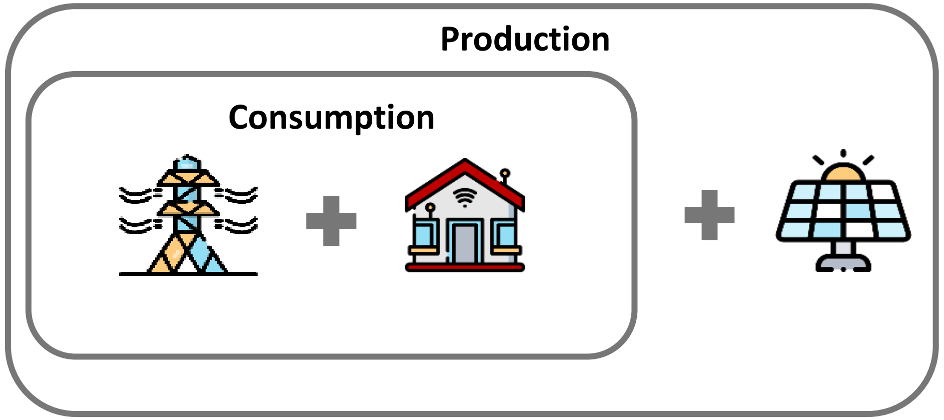

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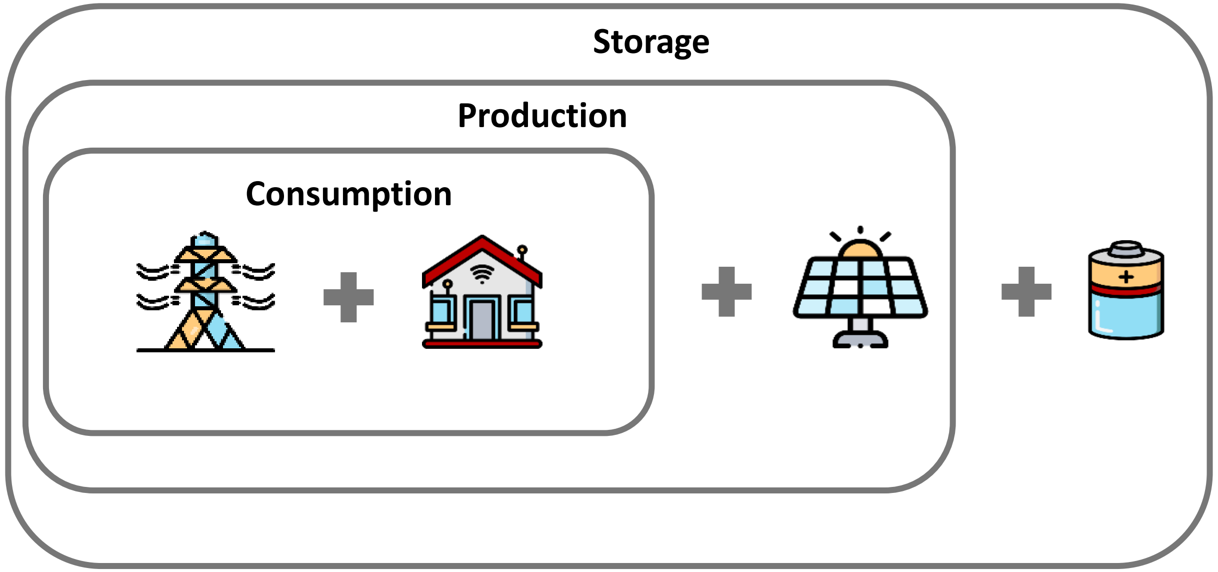

- Production units can be, e.g., photovoltaic, wind turbine, diesel generator.
- Storage units can be, e.g., batteries or electric vehicles.

Prosumers as Rational Agents

- Based on the available **properties**, agents are able to perform different **actions** per time step:

Agent	Property			Action	
	Consumption	Production	Storage	Market	Storage
a_{C}	√	×	×	√	×
$a_{\mathrm{C+}}$	√	×	√	√	√
a_{P}	×	√	×	√	×
$a_{\mathrm{P+}}$	×	√	√	√	√
a_{S}	×	×	√	√	√
a_{CP}	√	√	×	√	×
$a_{\mathrm{CP+}}$	√	√	√	√	√

→ However, not every action is allowed.

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a_{P}	×	√	×	√	×
a_{P+}	×	√	√	√	√
a_{S}	×	×	√	√	√
a_{CP}	√	√	×	√	×
a_{CP+}	√	√	√	√	√

→ However, not every action is allowed. **Some constraints need to be defined!**

Game Constraints

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- At every time step an agents‘ consumption $\ell_{C,t}^{(a)}$ needs to be covered:

$$\ell_{C,t}^{(a)} = \ell_{P,t}^{(a)} + \ell_{S,t}^{(a)} + \ell_{M,t}^{(a)}.$$

  Either by production $\ell_{P,t}^{(a)}$, storage $\ell_{S,t}^{(a)}$ or power grid $\ell_{M,t}^{(a)}$.
- Furthermore, the storage and production units have some bounderies:

$$-P_{max}^{(a)} \leq \ell_{P,t}^{(a)} \leq 0$$
$$0 \leq SOC_{t}^{(a)} \leq SOC_{max}^{(a)}$$
$$\ell_{discharge,t}^{(a)} \leq \ell_{S,t}^{(a)} \leq \ell_{charge,t}^{(a)}$$

- We **define** power flow to the agent as <u>negativ</u> values, e.g., produced electricity by PV panel.

Strategies and Utility

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- Every day an agent choose a **storage control strategy *σ*** from a given **strategy space *S***.
- We define two simple strategies with different behaviour.

1. **Spillover:** **Priorities the storage**. Overproduced electricity is used to charge the storage. If storage discharge is available, it is used to cover the household consumption.

2. **PriceDepending:** **Priorities the market price**. If the price for buying electricity is below a given threshold, always consume from the power grid. Or feed-in if the selling price is above the threshold.

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- **How can we evaluate the different strategies?**
  We define an utility function based on the total amount of money payed or earned c_t by an agent:

$$\pi_\sigma^{(a)} = \sum_t^T \ell_{M,t}^{(a)} \times c_t.$$

→ An rational agent tries to maximize this utility.

Nash Equilibrium for our Game

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- **Nash Equilibrium:** No agent can increase their utility by unilateral strategy change.
- We define the optimal strategies for all agents when the game reaches its Nash Equilibrium.

- To find this equilibrium state, an **iterative approach** is used:

Algorithm 3 Iterative Nash calculation

Input: Agents $\mathcal{A}$, Strategies $\mathcal{S}$, Iterations i

```
procedure NASH(𝒜, 𝒮, i)
    Initialize Agents A with random Strategy from S
    count ← 0
    while count < i do
        for all a ∈ A do
            P empty list of length |S|
            for all σ ∈ S do
                π(σ) ← CALCULATEPAYOFF(a, σ)
                P ← P + π(σ)            ▷ Append π and σ to list
            end for
            σ_max ← max(P)              ▷ Strategy with max. payoff
            a(σ) ← σ_max                ▷ Set σ_max as agent's strategy
        end for
        count ← count + 1
    end while
end procedure
```

Price of not knowing the Future

- Based on the previous determined **optimal strategy**, we calculate the **Price of not knowing the Future**.
- This is the **utility difference** between optimal strategy and another strategy – an almost optimal one. **Other strategy selection methods:** *Yesterday's best*, *Steady* (always the same), *No Battery Usage*.

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- Results of our game with three agents for the different market types over a **whole week** MON-SUN:

Agent	Equipment	Strategy Selection	Market			Price of not knowing the future		
			Demand-Offer	Time-of-Use	Hybrid	Demand-Offer	Time-of-Use	Hybrid
$a^{(0)}$	$C = 290.87\,kW$	Optimal	-29.45	$-30,49$	$-28,28$	–	–	–
	$P = -73.17\,kW$	Yesterday	-29.55	$-30,49$	-28.36	0.10	**0**	0.08
	$P_{max} = 1.7\,kWp$	Steady	-29.54	-30.49	-28.34	**0.09**	**0**	**0.06**
	$SOC_{max} = 2\,kWh$	No Battery	-29.82	-30.86	-28.63	0.37	0.37	0.35
$a^{(1)}$	$C = 151.05\,kW$	Optimal	-11.19	-11.76	-10.88	–	–	–
	$P = -63.83\,kW$	Yesterday	-11.43	-11.92	-11.11	0.24	**0.16**	0.23
	$P_{max} = 1.36\,kWp$	Steady	-11.20	-11.97	-10.90	**0.01**	0.21	**0.02**
	$SOC_{max} = 2\,kWh$	No Battery	-12.73	-13.17	-12.25	1.59	1.41	1.37
$a^{(2)}$	$C = 170.74\,kW$	Optimal	-14.32	-14.44	-13.57	–	–	–
	$P = -68.73\,kW$	Yesterday	-14.46	-14.44	-13.70	0.14	**0**	0.23
	$P_{max} = 1.48\,kWp$	Steady	-14.37	-14.44	-13.61	**0.05**	**0**	**0.04**
	$SOC_{max} = 2\,kWh$	No Battery	-15.56	-15.68	-14.80	1.24	1.24	1.23

Conclusion & Future Work

- A **game of prosumers** represented as **rational agents** is defined.
- These agents are **classified** based on their **properties** that lead to certain **actions**.
- Two basic **strategies** with different utilization goals are given.
- An **optimal strategy** for an agent within this game is determined by calculating the **Nash Equilibrium**.
- Three other strategy selection methods are presented.
  The utility difference is defined as the **Price of not knowing the Future**.

- **Future Work:**
  - Further developments and improvements for optimization process.
  - Definition and implementation of broader strategy space.
  - Simulation different game settings with more agents and/or whole real-world grid structures.
  - Long-term analyses in terms of grid stabilization and reliability.

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Thank you very much!

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