Control concepts for the development of bi-directional heating networks

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from thermal management to hydraulic control of decentralized heat producers

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Overview

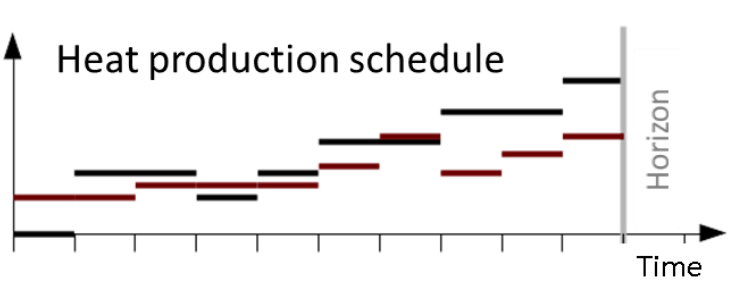
- **The Need for Load Management**
- **Hydraulic Control**
- **A Synopsis of Load Management Strategies**
- **Model Predictive Control:**
  - Concept
  - Simulation
  - Implementation
- **Free Market Model**
- **Summary and Outlook**

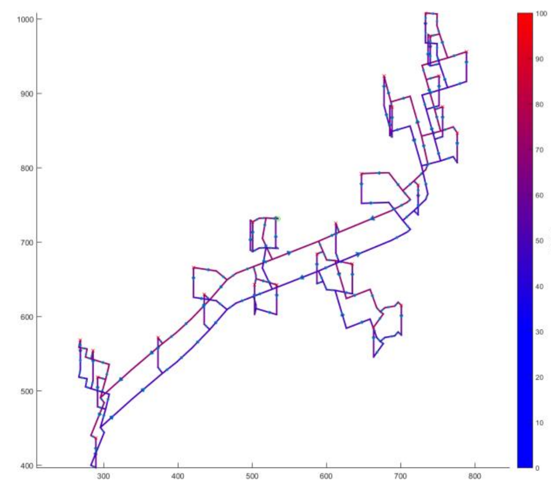
The Need for Load Management

- **Producers need to know when to provide heat and how much**
- **Minimize heat generation costs**
  - (Biomass) fuel, electrical energy for pumps and heat pump
- **Minimize losses**
  - Cooldown of hot water in buffers and in grid
- **Minimize emissions**
  - Avoid frequent on/off-switching of producers, prefer nominal operating conditions
- **Prevent supply shortage**
  - Provide sufficient feed temperature, keep buffers filled for worst-case scenario

The Need for Load Management: Levels of Control

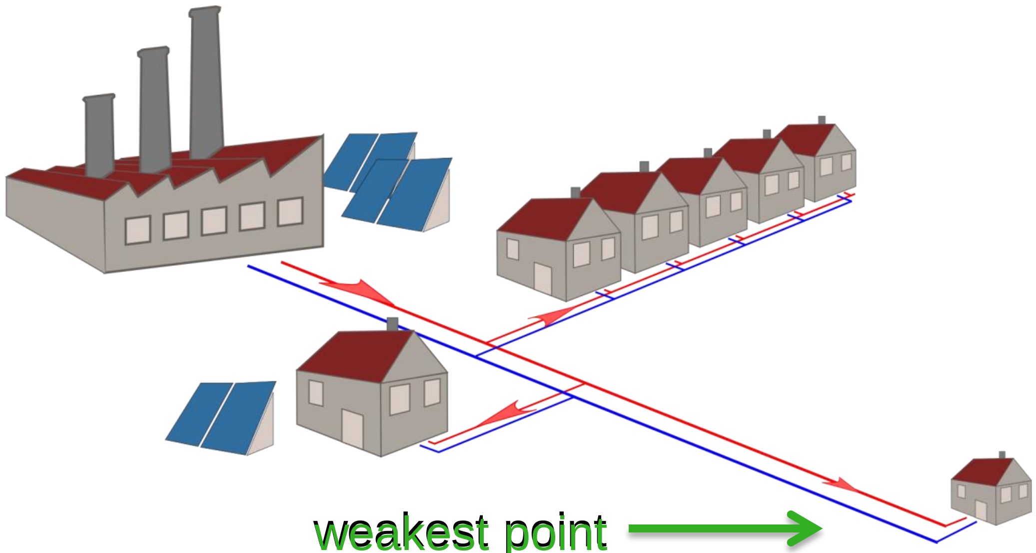
- **The control problem for multi-producer bi-directional heating grids can be separated into two layers:**
  - **Load Management** (superordinate control, high-level control): Decide when to turn on and off which heat producer, set target values for heat production → production schedule
  - **Hydraulic Control** (subordinate control, low-level control): Provide hydraulic conditions (pressure levels, temperature levels, mass flows etc.) so that the produced heat is transferred to the consumers





Hydraulic Control: Problem Description

- **Task**
  - Every producer feeding heat into the network must maintain **pressure levels** and **minimum feed temperature**
- **Challenges**
  - Classical approach of pump control does not work (constant pressure difference at “weakest” point)



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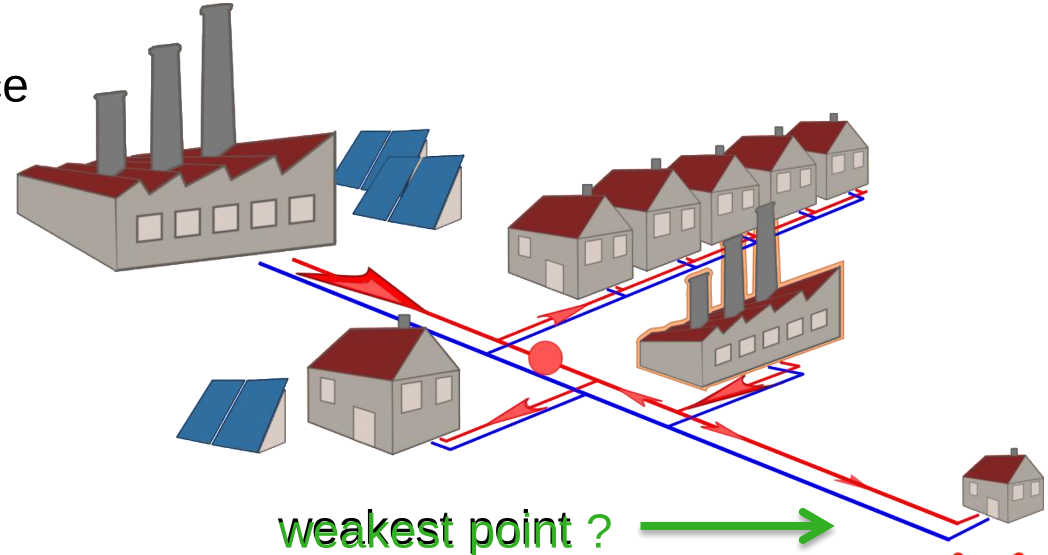
  - Risk of stagnation points



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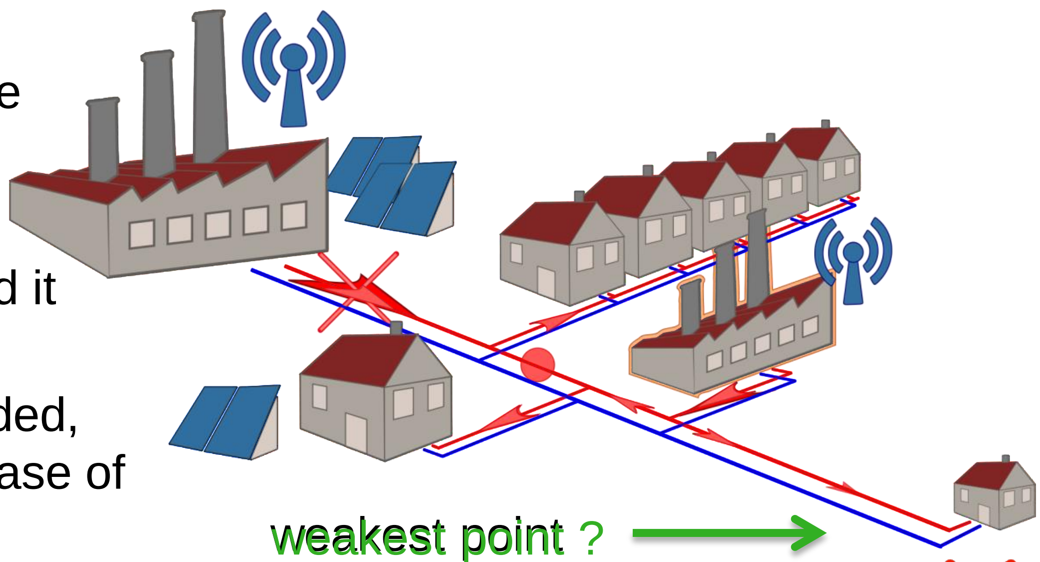
  - Risk of pressure oscillations and inter-producer interference
  - Risk of stagnation points
  - Cannot get rid of surplus heat if no consumers currently need it
  - Strategy for communication with load management is needed, including fallback solution in case of communication failure



Hydraulic Control: Approaches

- Two main approaches:
  - **Centralized**: All pumps and valves controlled by one central controller
    - does not scale well, main problem: high information transmission times
    - implementation e.g. via model-based control strategy
  - **Distributed**: Classical PID controller at each producer. Control of…
    - mass flow fed into the network
      if heat cannot be stored locally
    - pressure difference at currently relevant "weak point"
      if heat can be stored locally
- Currently, different control strategies are validated and evaluated in **simulations** using hydro- and thermodynamic models of the heating grid
- Best strategies will be implemented on **real system** in summer 2017

A Synopsis of Load Management Strategies: Concepts

- Concepts for Load Management Strategies:

authoritarian

- **Complete Central Access**: Single central instance has complete control over all actuating variables
- **Central Targets**: Central instance communicates target values for heat production to the prosumers
- **Central Decision**: Prosumers communicate heat demand and production costs, central decision
- **Decentralized Decision**: Central instance defines a fair price for feed-in, prosumers decide autonomously
- **Free Market**: Prosumers communicate their marginal production costs and arrange bilateral transactions

autonomous

A Synopsis of Load Management Strategies: Comparison

Aspect	Central (Authorit.)	Decentralized (Auton.)
System performance	possibly optimal	reasonably good*
Security of supply	high	low to high**
Autonomy	low	high to low**
Vulnerability to attacks***	critical central node	moderate
Hydraulic complexity	high	moderate
Scaling properties	usually bad	moderate
Computing power (central)	high	low/none
Computing power (prosumer)	low	moderate

* Price-based strategies are susceptible to formation of syndicates.
** depending on the legal framework
*** All approaches depend on a working communication structure.

A Synopsis of Load Management Strategies: Concepts under consideration

- Two exemplary strategies presented in this talk:

authoritarian

autonomous

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To be implemented in Großschönau

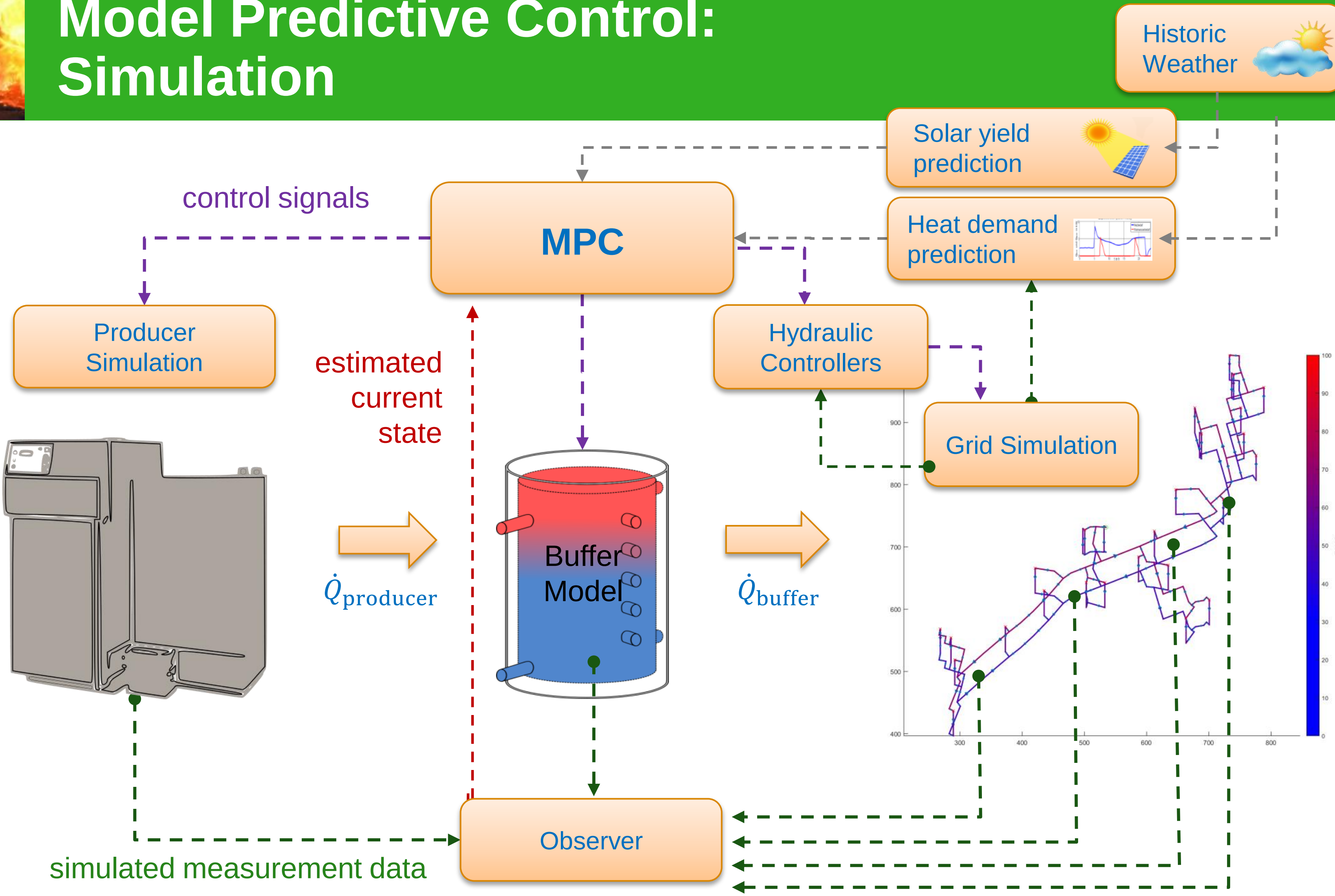
Further investigation in simulations

Model Predictive Control (Central Targets): Concept

Model Predictive Controller

- Determine the **state** of the system
  - heat stored in buffer, temperatures and mass flows in the grid, current output of the producers
- Use **mathematical models** of producers, buffers, heat pumps and the grid to **predict** future behavior using
  - a **prediction of the heat load** required by the consumers
  - a **prediction of the solar yield** of the solar collectors
- Find operation strategy for the next 24h minimizing future costs while guaranteeing sufficient heat supply
- Apply this strategy for a specific time, e.g. 15 min
- Use measurements to compare actual with predicted behavior and update state estimate accordingly

Model Predictive Control: Simulation



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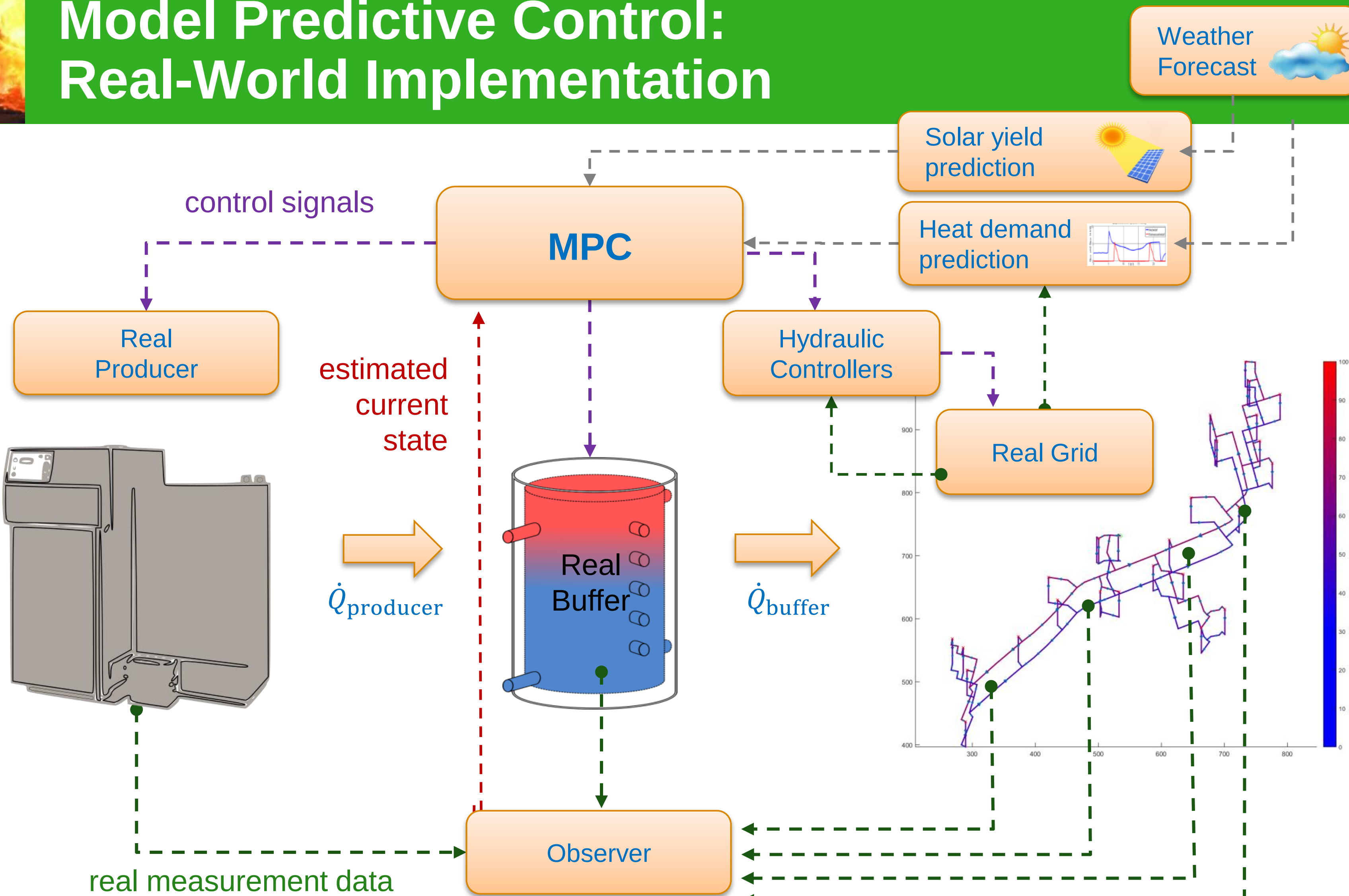
Model Predictive Control: Real-World Implementation



Free Market Model

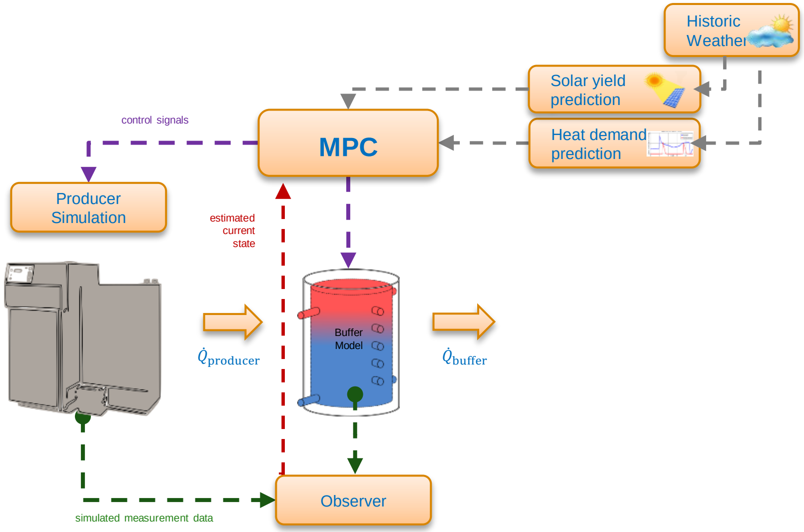
Alternative approach: Free Market Model

- Basic agent: **prosumer** (cluster), characterisation of
  - Controllable production with associated production prices
  - Independent production (e.g. solar, waste heat)
  - Heat consumption profile
  - Heat storage capacity

- Optimization algorithm consists of **two stages**, consecutively executed at each timestep:
  1. **Individual** optimization of heat production schedule
  2. Further optimization by **bilateral transactions**

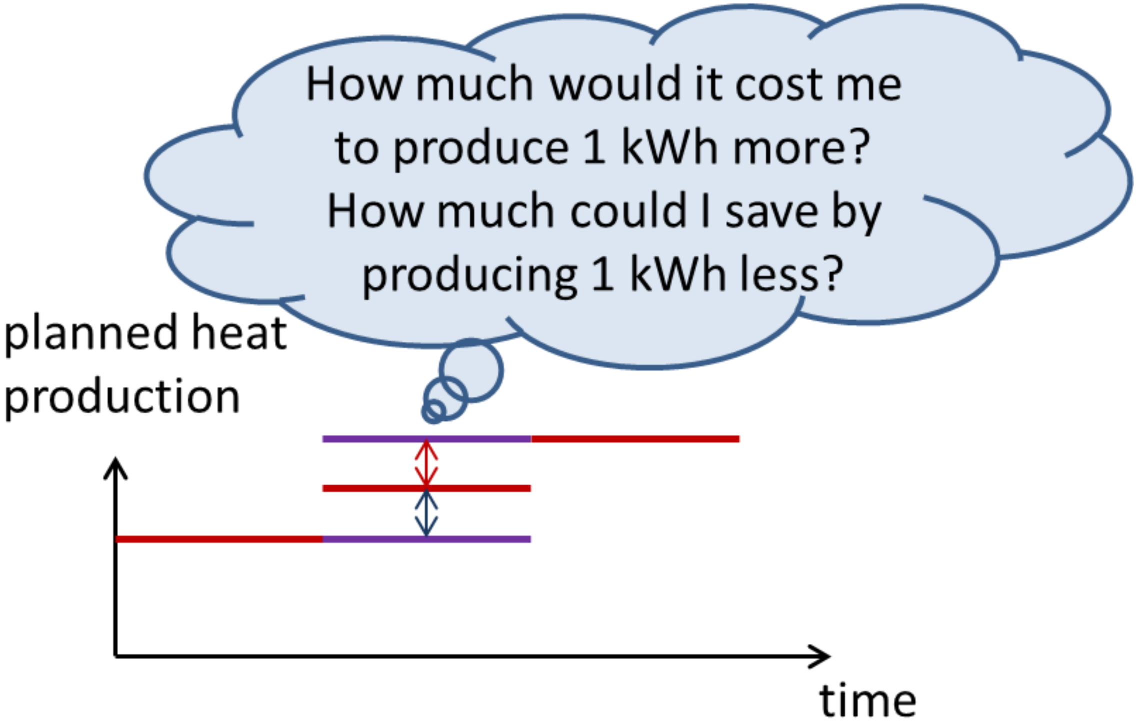
Free Market Model: Step 1

- **Individual optimization of heat production schedule**
  - Perform (model-predictive) optimization for individual heat production, making use of load forecasts etc.
  - Similar to approach presented before, but for a much smaller system



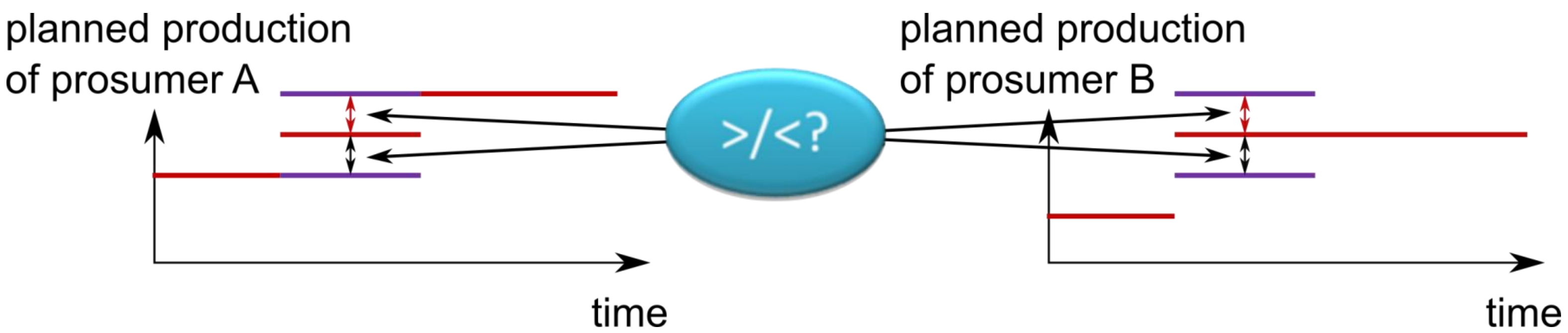
Free Market Model: Step 2 (I)

- **Further optimization by bilateral transactions**
  - Each prosumer calculates marginal costs for heat production for each timestep within the prediction horizon:



Free Market Model: Step 2 (II)

- Compare marginal costs for all pairs of prosumers and check how costs could be reduced by bilateral transactions



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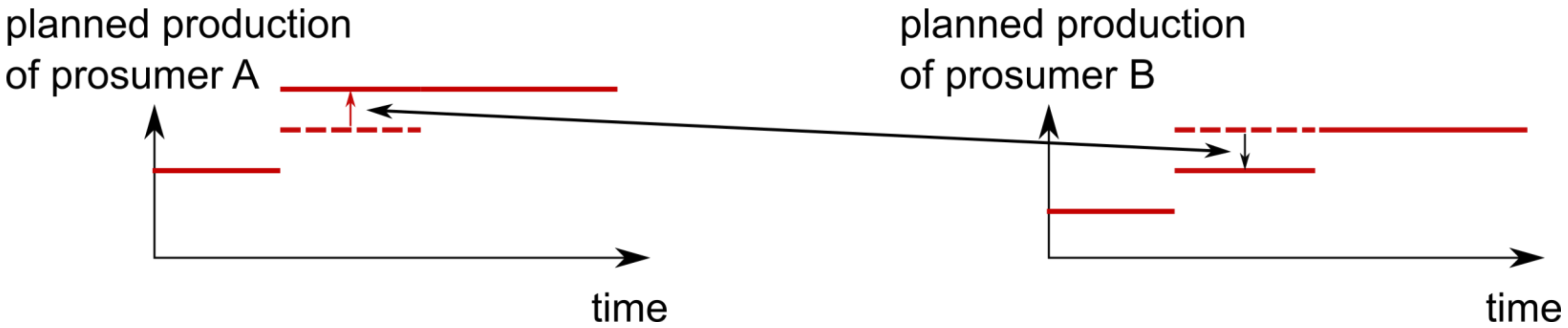

- Find best transaction and fix it → binding agreement
- Split savings in a fair way between the two protagonists
- Repeat this process until no improvement is possible

Free Market Model: Conclusion

- **Downside**: Optimization by bilateral transactions roughly corresponds to a “steepest-descent“ method
  - Local optimization not necessarily yields the global optimum
- The Market Model can be used either as a mere tool for optimization or as an actual **business model**
  - This also applies to all other price-based models with several protagonists

- Concepts for superordinate control:

  authoritarian

  - **Complete Central Access**: A single central instance has complete control over all actuating variables
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- Further studies on market-based models are currently being carried out

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Summary and Outlook (I)

- The successful integration of prosumers into bi-directional heating networks depends on **reliable control strategies**
- The **hydraulic control problem** for bi-directional grids is challenging: standard control strategies for heating grids cannot be directly applied to this case
- A **Load Management strategy** is necessary for reliable and efficient grid operation

Summary and Outlook (II)

- Both **centralized** and **decentralized** control appoaches have their advantages and disadvantages:
  - **Model predictive control** (with central target values) is the most promising strategy for the current practical implementation and will soon be implemented in a (small) heating grid
  - **Market-based models** have better scaling properties than centralized/authoritarian strategies and may thus be better suited for larger networks
- Market models based on marginal costs and bilateral transactions are currently under investigation and could als be used as **business models**

Promising approaches, but still many open questions…

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