Optimization-based Energy Management System for Hybrid Energy Networks

Conférences énergie-environnement automne 2020

Genève / Graz, 15th of October, 2020

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BEST – Bioenergy and Sustainable Technologies

- **Austrian (COMET-) competence centre for bioenergy and sustainable technologies**
- **3 locations & 1 research site**
  - Graz (head office), Vienna, Wieselburg, Tulln
- **Partners**

Covering all relevant conversion technologies and cross-sectional areas

Area 4
CFD Modelling and Simulation

Area 5
Energy and Bioeconomy Systems

Sub-Area 5.1
Sustainable Supply and Value Chains

Sub-Area 5.2
Smart and Microgrids

Sub-Area 5.3
Automation and Control

Area 1
Fixed Bed Conversion Systems

Area 2
Fluidized Bed Conversion Systems

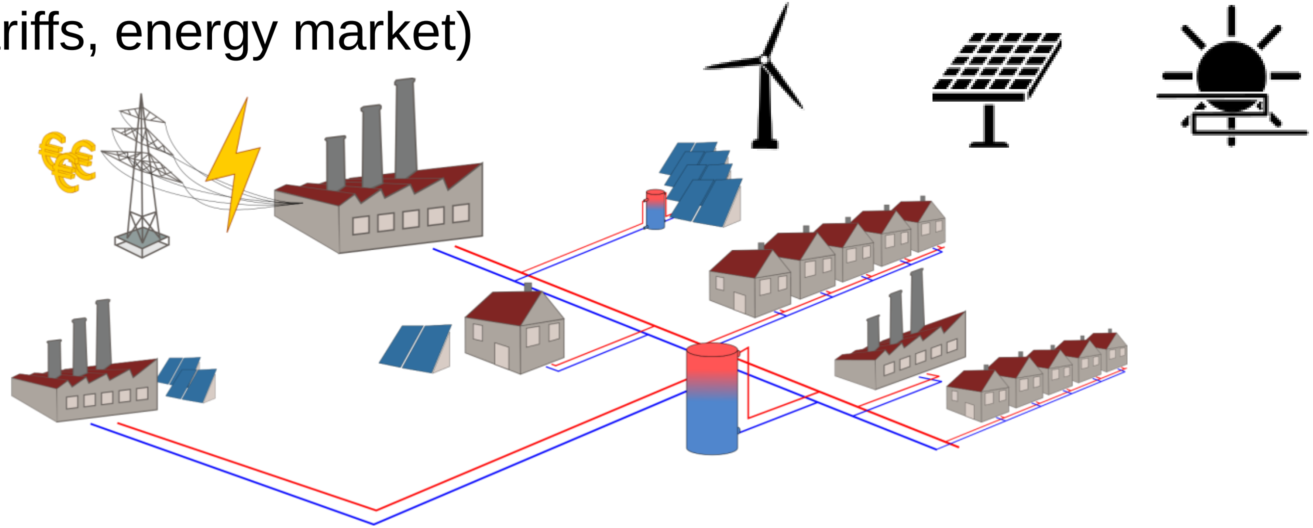
Area 3
Bioconversion and Biogas Systems

Infrastructure: Lab services and supporting RTD / development of analytical and measurement methods

Challenges of hybrid energy networks

Growing complexity of **integration in networks** (variable tariffs, energy market)

Integration of **renewable**, but **volatile** energy sources



Increased **coupling** between sectors

Need to ensure **economical** and **ecological** energy supply

Computer Support via Optimization

years

Planning

minutes → days

Operation

Unit Commitment / Economic Dispatch

SCADA

Low-level Control

Data Communication

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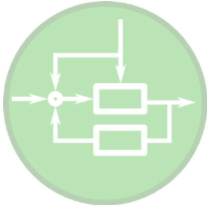
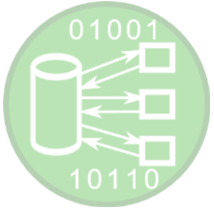


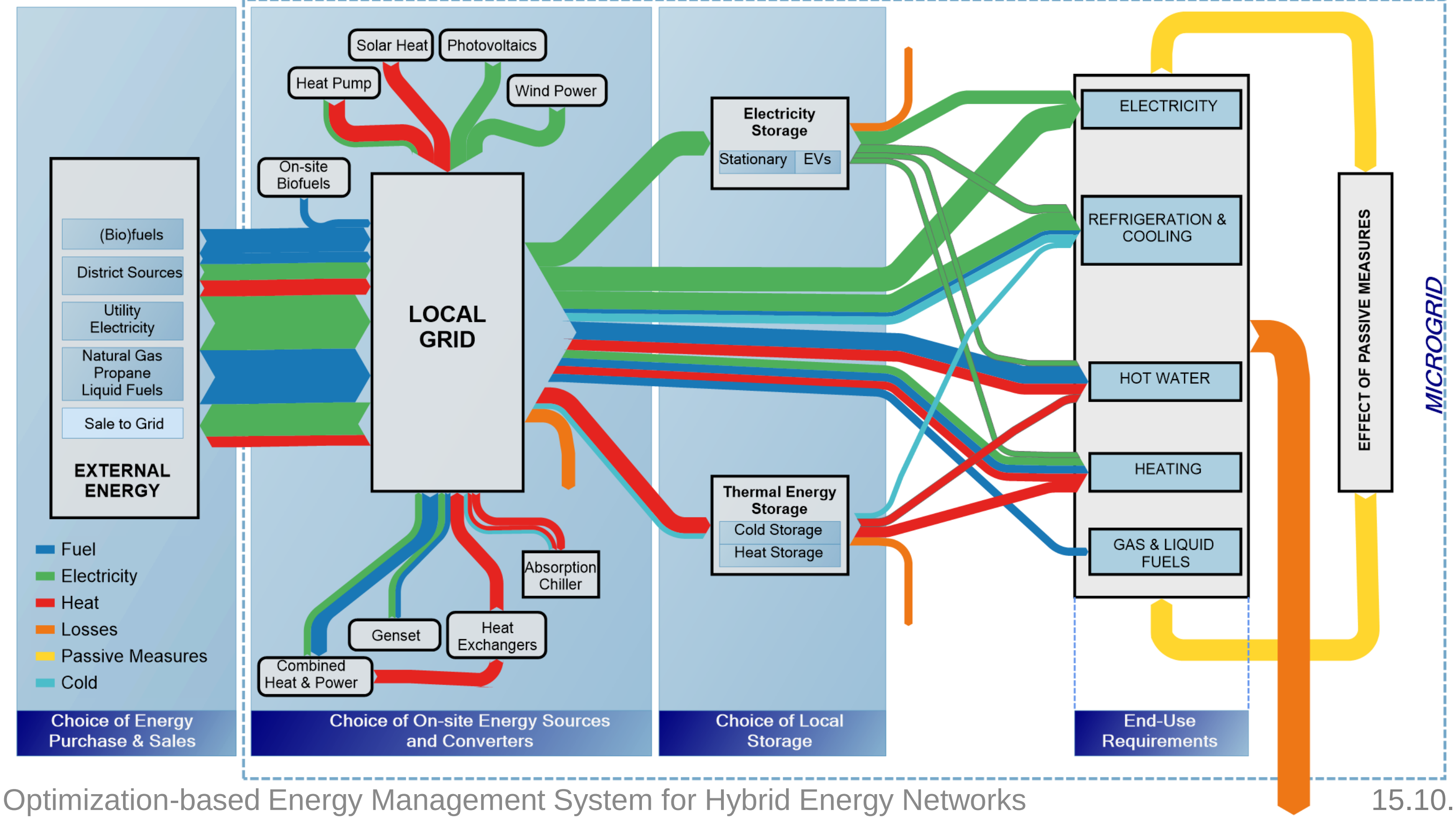
Low-level Control

SCADA



Data Communication

Planning



Solar Heat
Photovoltaics
Heat Pump
Wind Power
On-site Biofuels
LOCAL GRID
Electricity Storage
Stationary
EVs
(Bio)fuels
District Sources
Utility Electricity
Natural Gas Propane Liquid Fuels
Sale to Grid
EXTERNAL ENERGY
ELECTRICITY
REFRIGERATION & COOLING
HOT WATER
HEATING
GAS & LIQUID FUELS
EFFECT OF PASSIVE MEASURES
MICROGRID
Thermal Energy Storage
Cold Storage
Heat Storage
Absorption Chiller
Genset
Heat Exchangers
Combined Heat & Power
Fuel
Electricity
Heat
Losses
Passive Measures
Cold
Choice of Energy Purchase & Sales
Choice of On-site Energy Sources and Converters
Choice of Local Storage
End-Use Requirements

Combinatorial Optimization for Planning

- Define **base case configuration** and **boundary conditions** (e.g. prices, tariffs, available area)
- Define **typical demand** and **yield data**:
  month ⊗ (hours of day) ⊗ {week, weekend, peak}
- Define **objective function**:
  - minimize costs (annualized investment + operation)
  - OR minimize CO_2 emissions
  - OR use combination (and perform *Pareto analysis*)
- Automatically check all possible combinations of technologies, find **optimal size of components** and **typical operating schedule**

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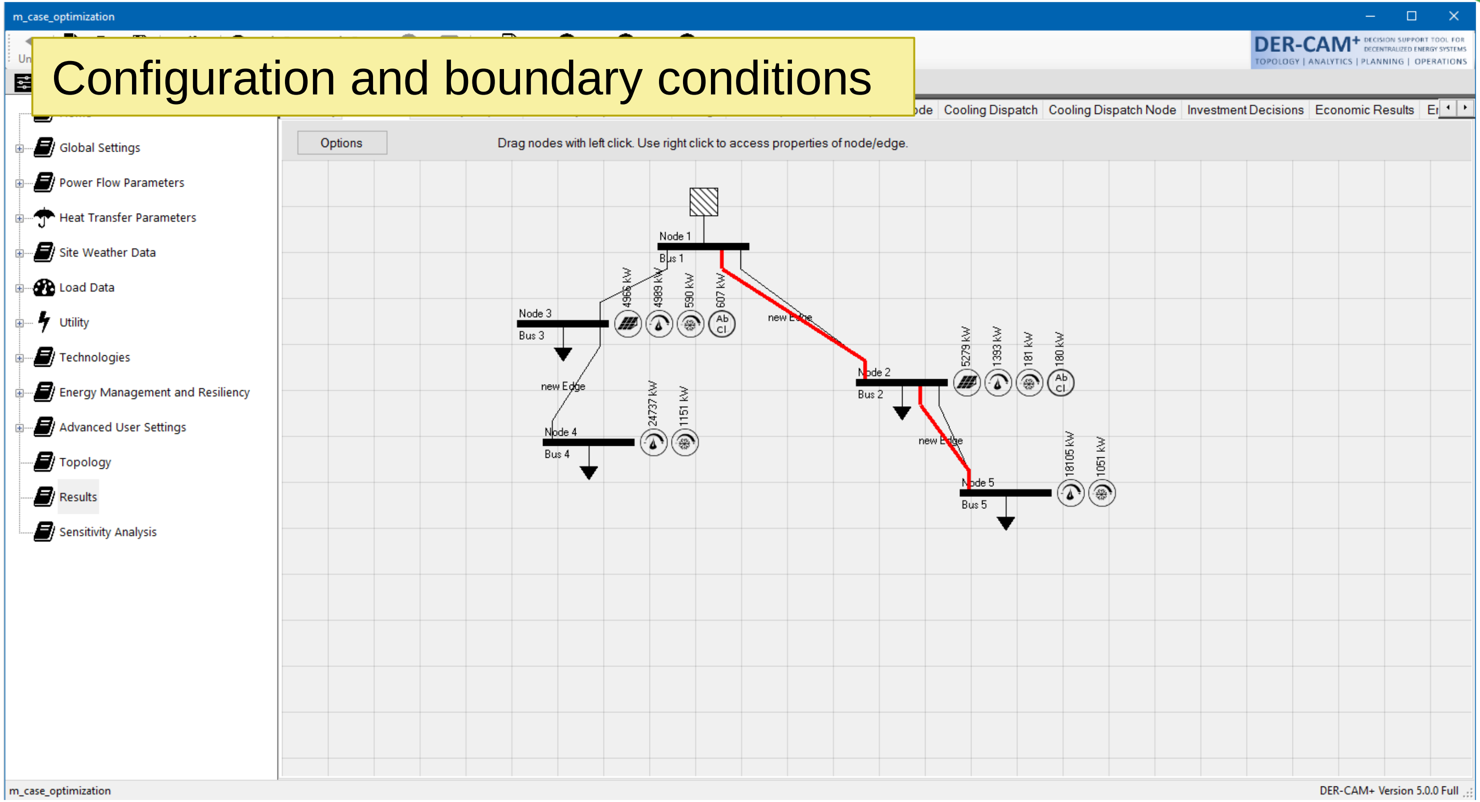
SOLVER

Combinatorial Optimization for Planning



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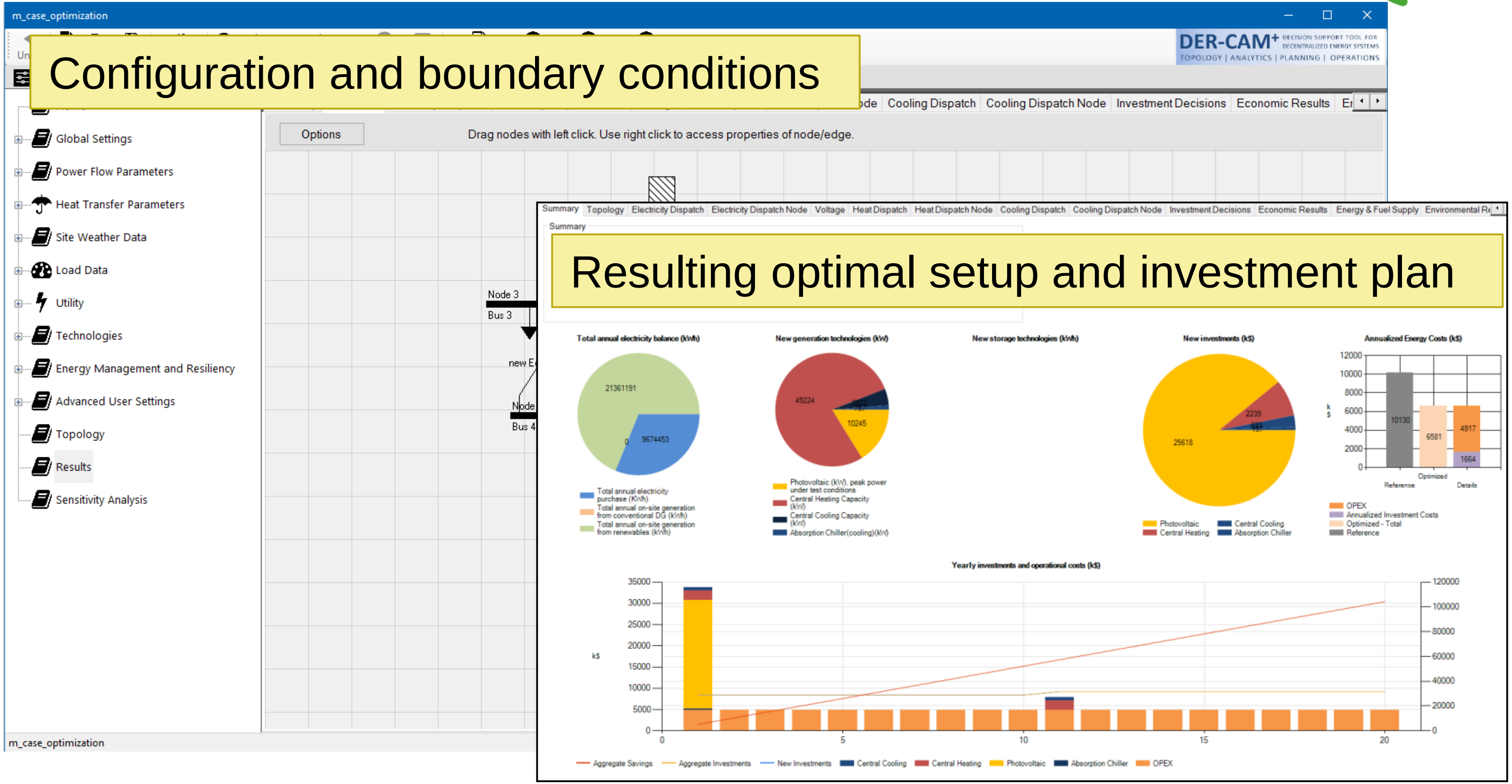

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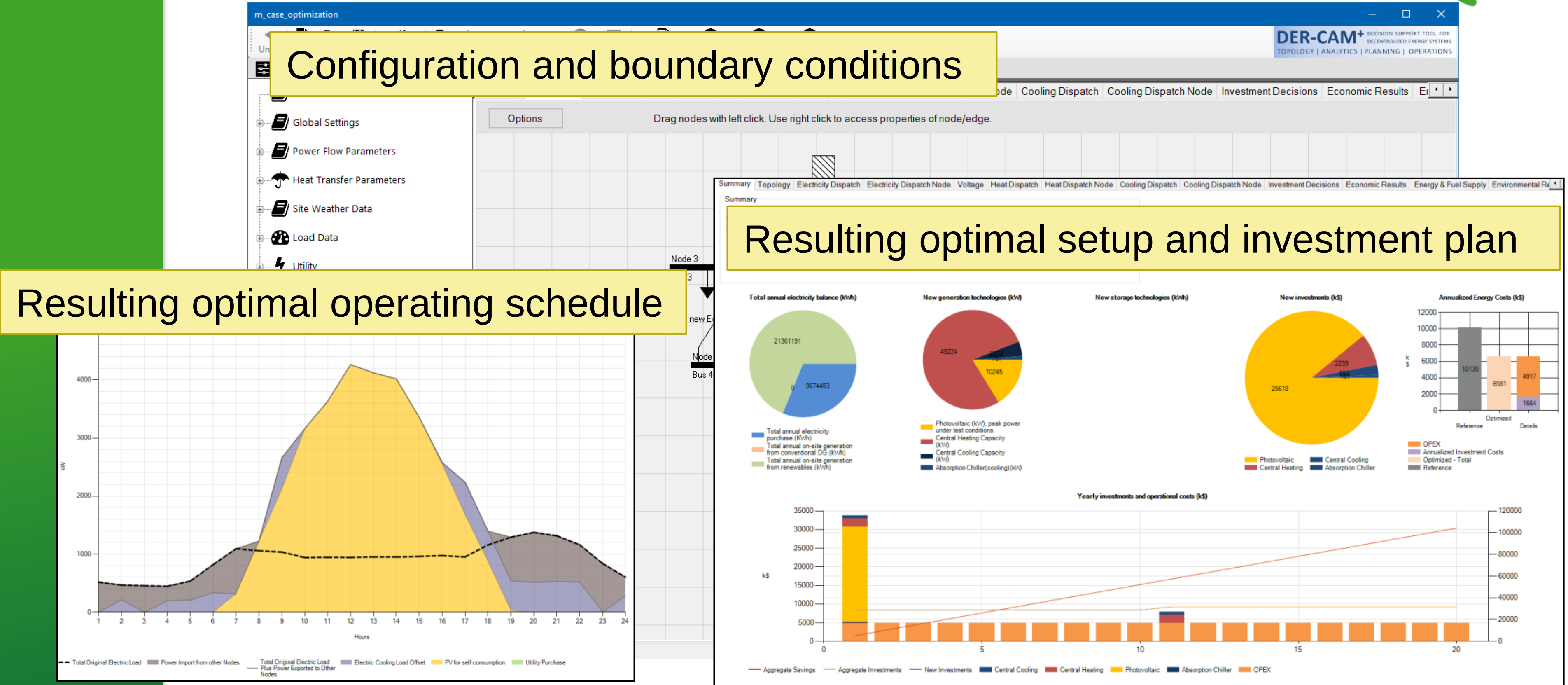

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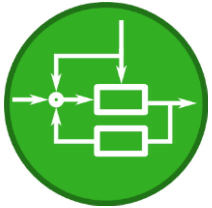
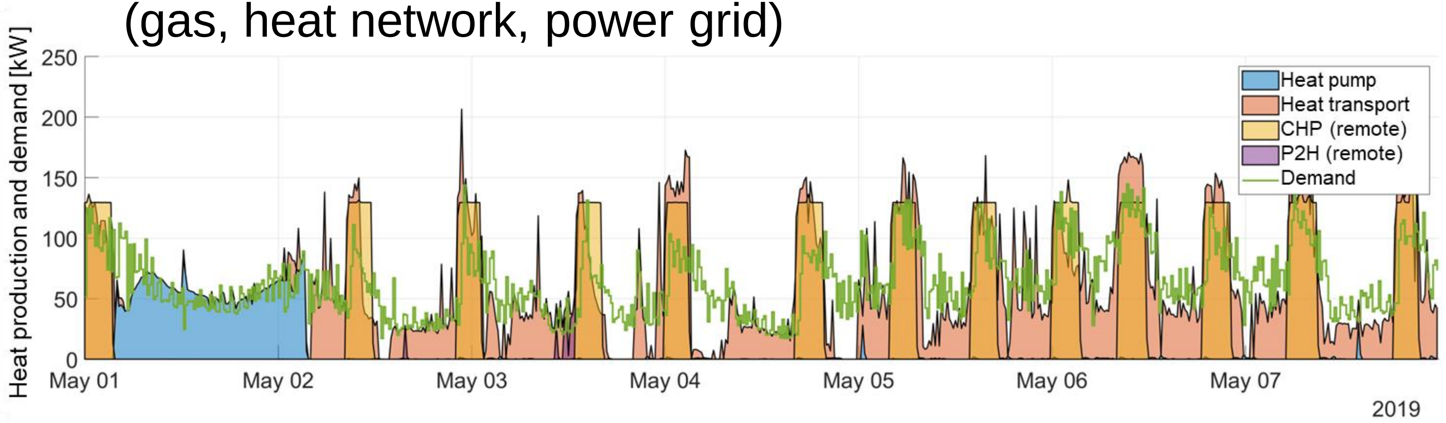


Low-level Control

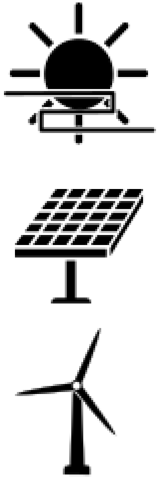
Data Communication

Operation:
Energy Management System (EMS)

- **The EMS delivers an Operating Strategy**
  - Unit dispatch (on/off), set points
  - Charging / discharging of (thermal) storages and batteries
  - Selling / purchasing energy from networks (gas, heat network, power grid)



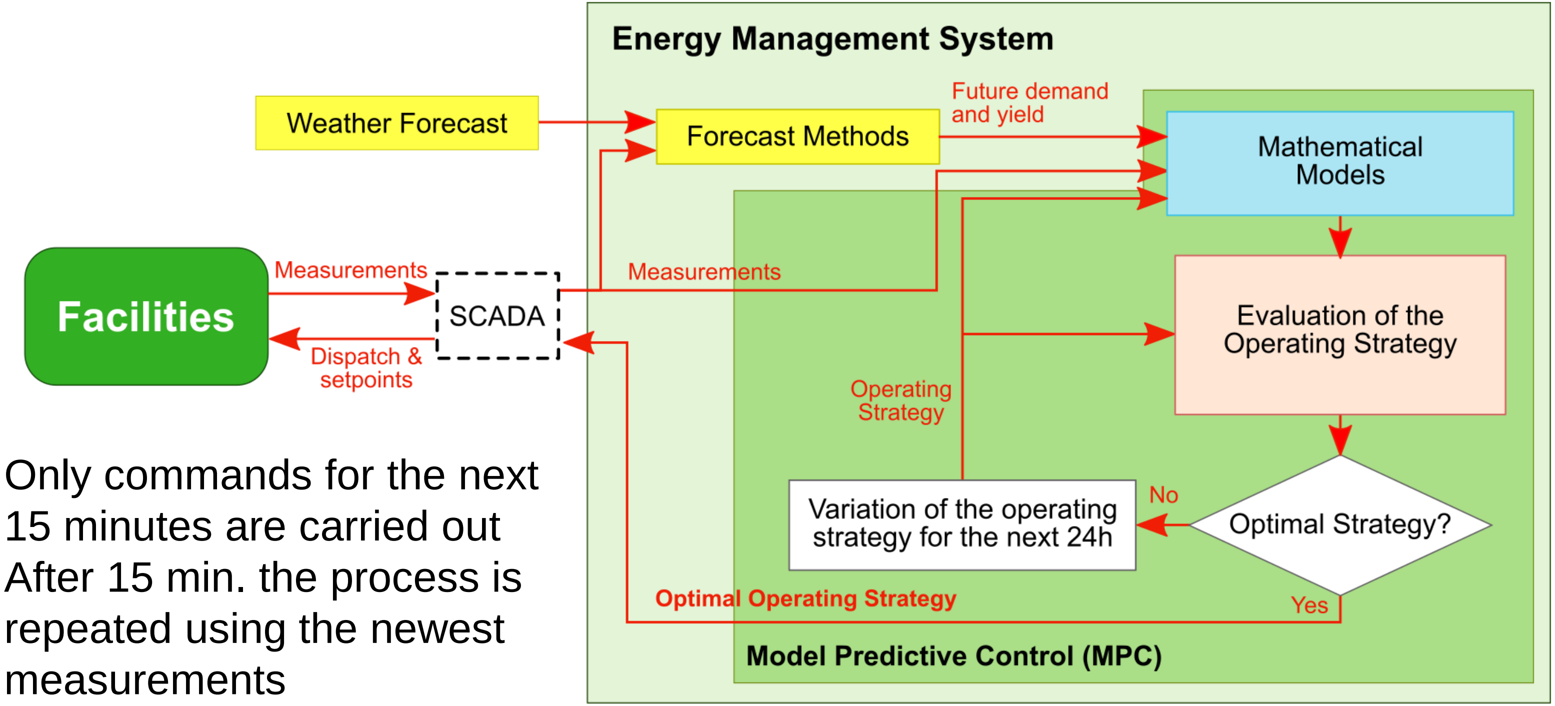
Motivation for Predictive Control Strategies



- We need a **forecast** of the yield from renewable sources, of the energy demand and tariffs…
- … for an effective **buffer & battery management** …
- … and a cost-efficient **unit commitment** of the producers

→ **We need a predictive control strategy**

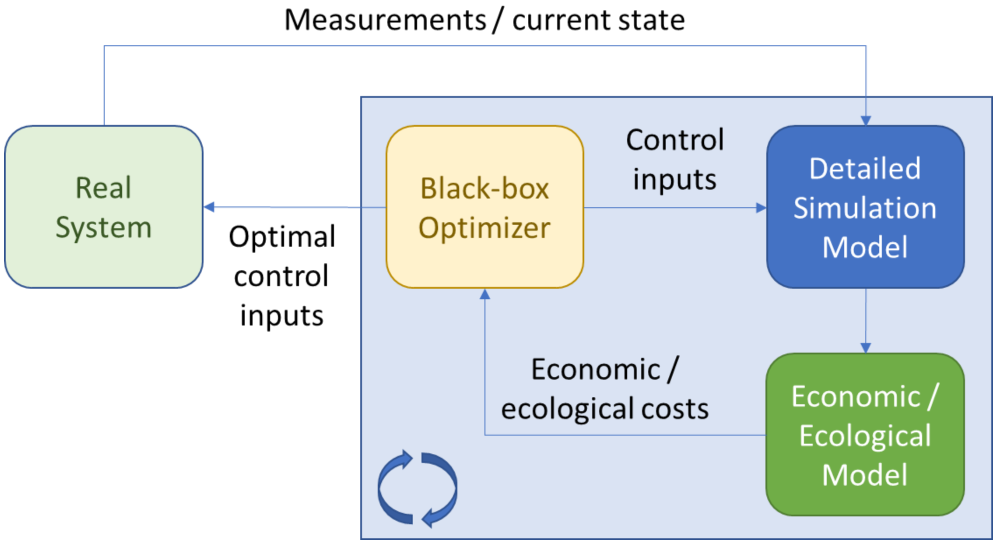
Principle: Model Predictive Control



- Only commands for the next 15 minutes are carried out
- After 15 min. the process is repeated using the newest measurements

→ „**Moving horizon**“- principle   Optimization → Control

Types of Optimization / Models



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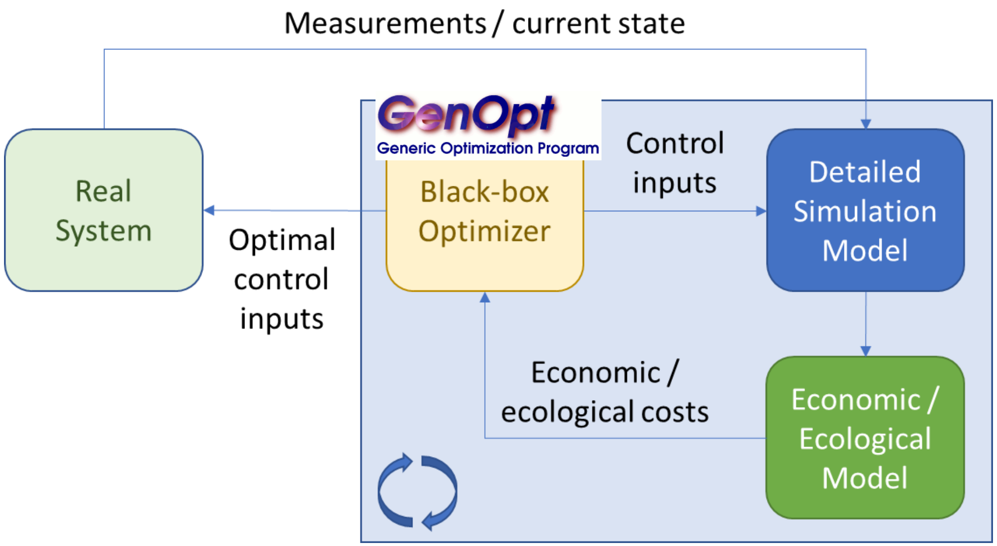

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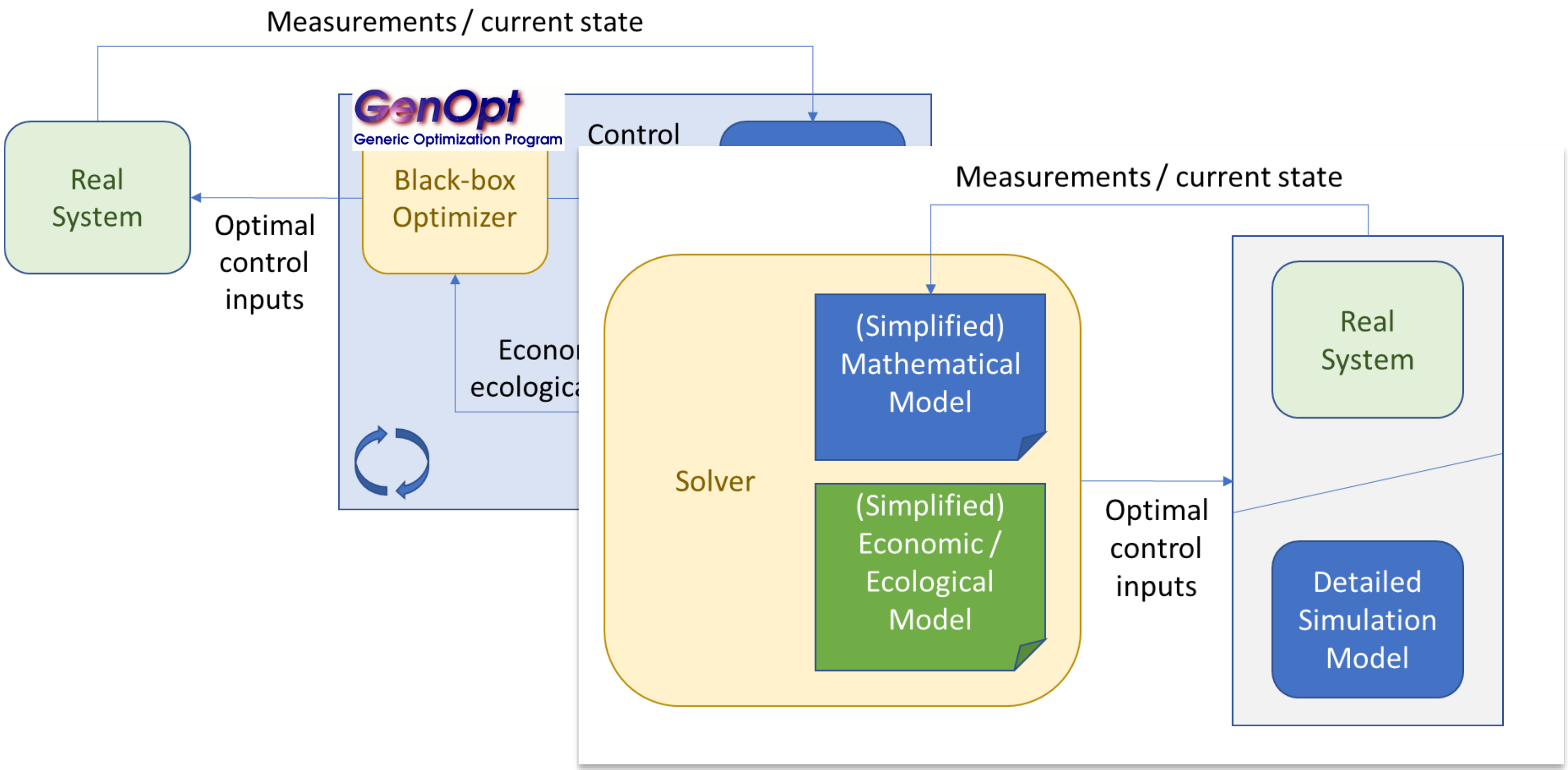

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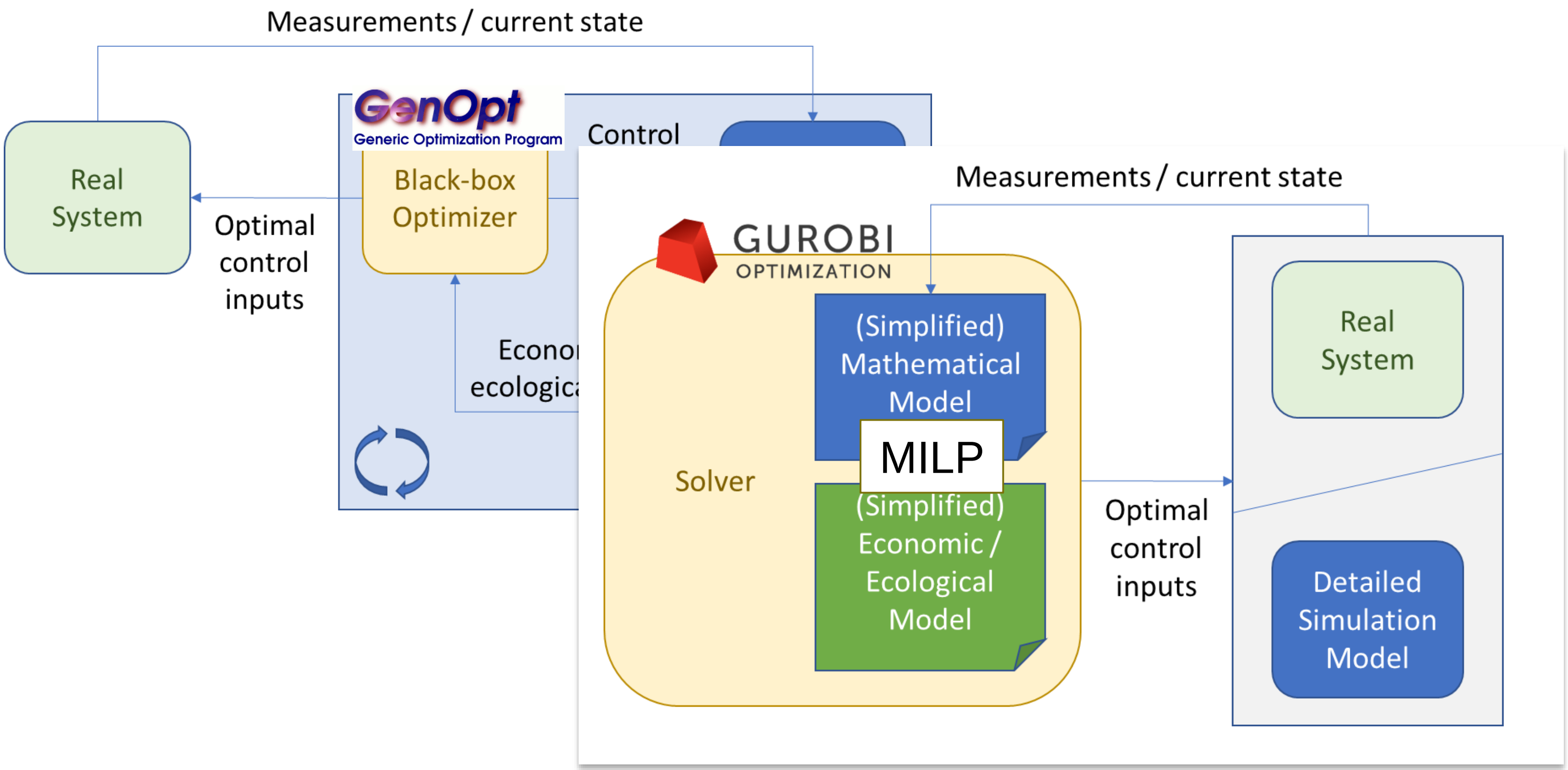

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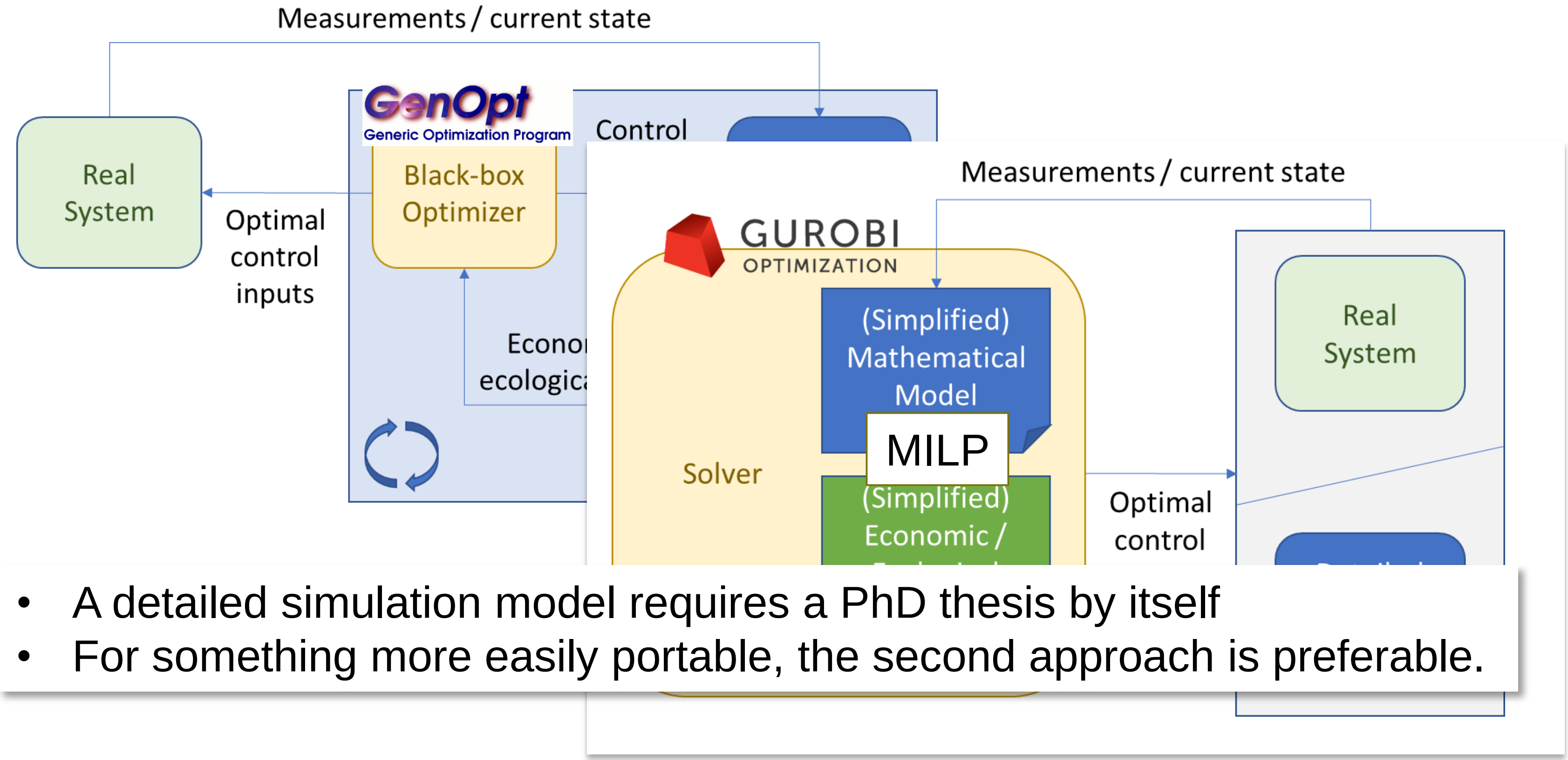
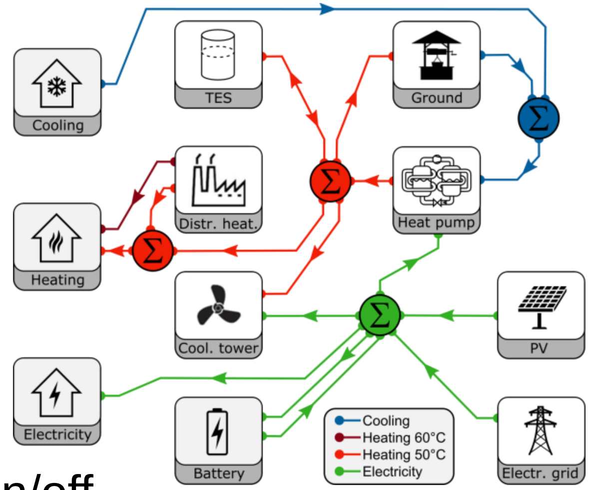


- A detailed simulation model requires a PhD thesis by itself
- For something more easily portable, the second approach is preferable.

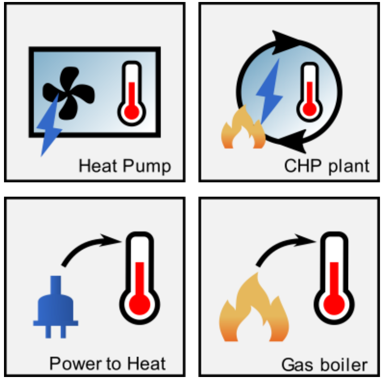
Energy Management System
Modular Framework

- **The operating strategy is derived automatically from a given configuration**
  - Simply connect **standard building blocks** for typical technologies (“prosumers”) (gas boiler, CHP, thermal storage , …)
  - Parametrize prosumers: Costs, minimum on/off times, ramping constraints, storage capacities
  - The connections ensure mass and energy balance and restrictions on transport



Mathematical representation of individual components (I)

- **Components are modelled as Mixed Logical Dynamical systems (MLD)**[1]
  - Linear, time invariant, **hybrid** system representation
    - Dynamics may depend on state or input
    - Piecewise affine approximation of nonlinear efficiency characteristics possible
  - **Binary + continuous** auxiliary variables and linear inequality constraints
    - Come “for free” when formulating Mixed Integer Linear Program

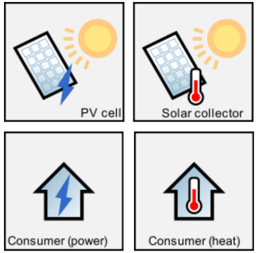


$$\mathbf{x}(k+1) = \mathbf{A}\,\mathbf{x}(k) + \mathbf{B}_u\mathbf{u}(k) + \mathbf{B}_\delta\boldsymbol{\delta}(k) + \mathbf{B}_z\mathbf{z}(k) + \mathbf{B}_w\mathbf{w}(k)$$
$$\mathbf{y}(k) = \mathbf{C}\,\mathbf{x}(k) + \mathbf{D}_u\mathbf{u}(k) + \mathbf{D}_\delta\boldsymbol{\delta}(k) + \mathbf{D}_z\mathbf{z}(k) + \mathbf{D}_w\mathbf{w}(k)$$
$$\mathbf{E}\,\mathbf{x}(k) + \mathbf{E}_u\mathbf{u}(k) + \mathbf{E}_\delta\boldsymbol{\delta}(k) + \mathbf{E}_z\mathbf{z}(k) + \mathbf{E}_w\mathbf{w}(k) \le \mathbf{g}$$

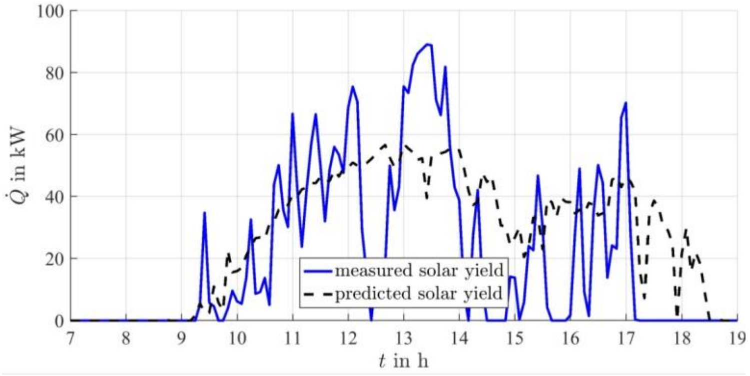
outputs — state — control signals — auxiliary variables (binary and continuous) — known / predicted disturbances

[1] A. Bemporad and M. Morari: Control of systems integrating logic, dynamics, and constraints. Automatica 1999

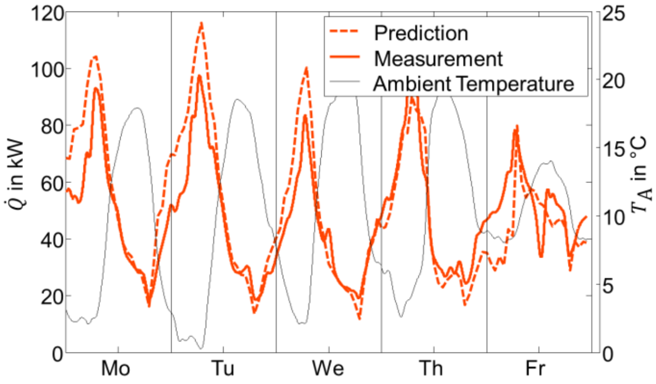
Mathematical representation of individual components (II)



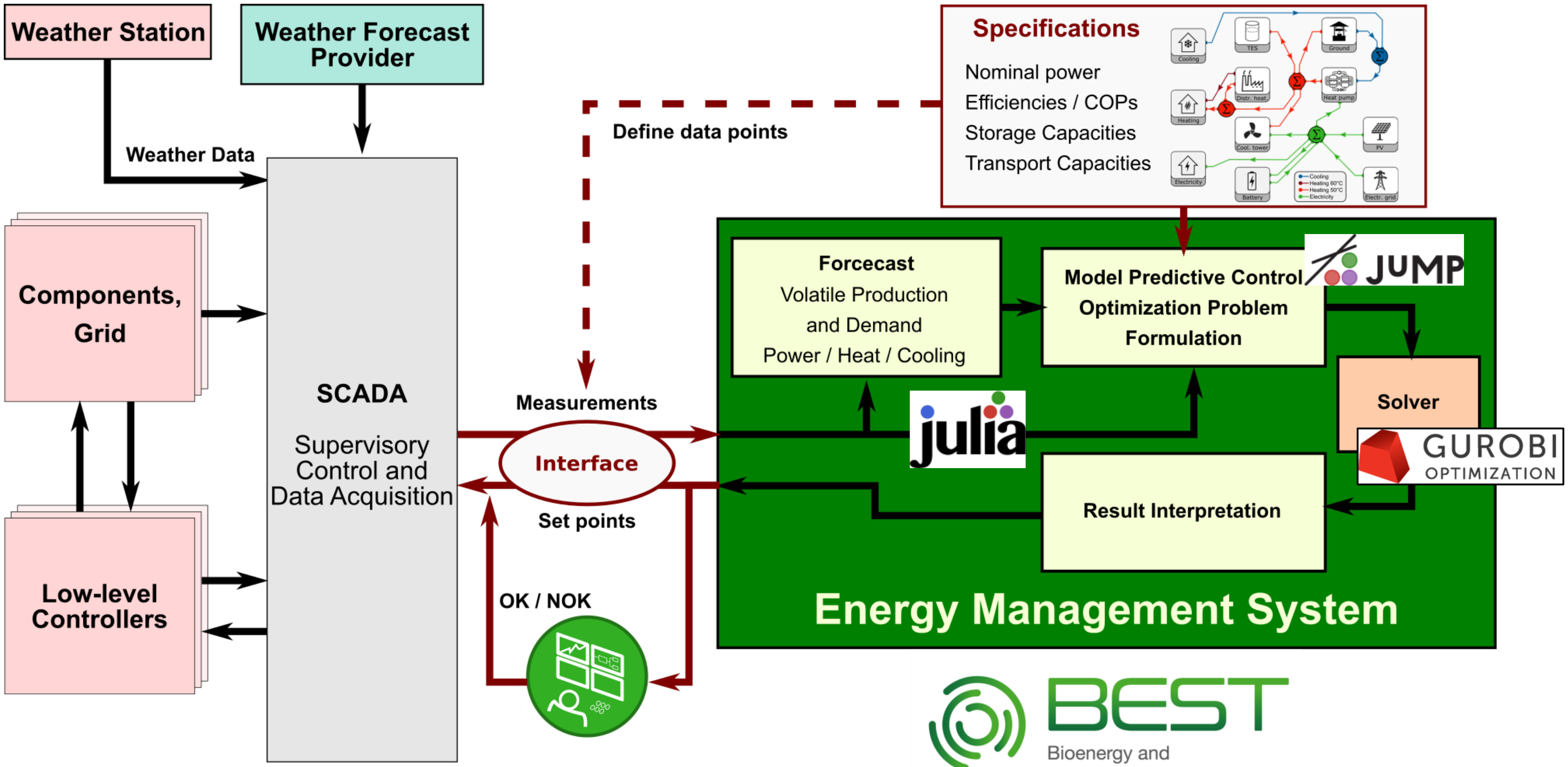
- **Fluctuating sources (renewables) and sinks (heat and power demand) use prediction models**
  – Adaptive, self-learning
    - Only require **past measurement data** and **future weather forecast**
    - No parametrization



Office building with a connection rating of 300 kW



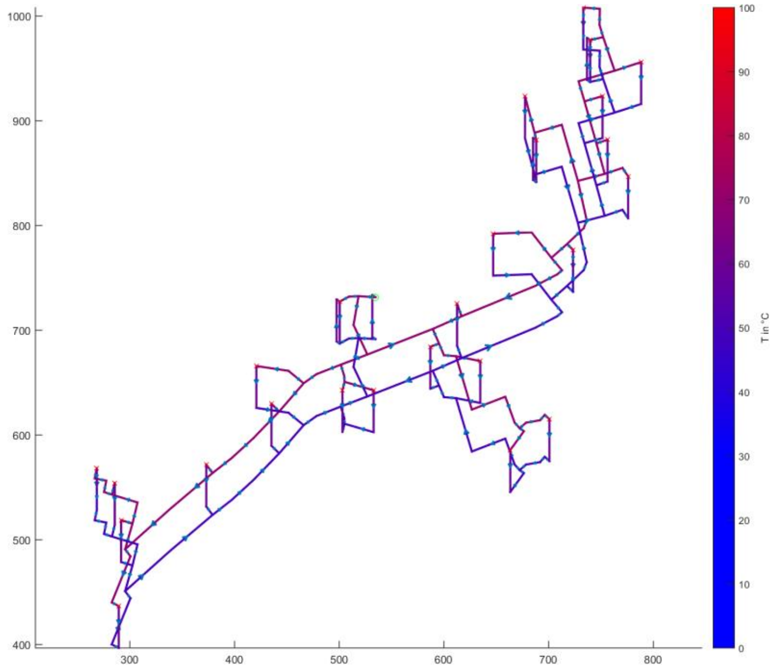
Steps Towards an Implementation



BEST
Bioenergy and Sustainable Technologies

Implementations

- **First demonstrator at small heating grid in Großschönau**
  - Proof of concept



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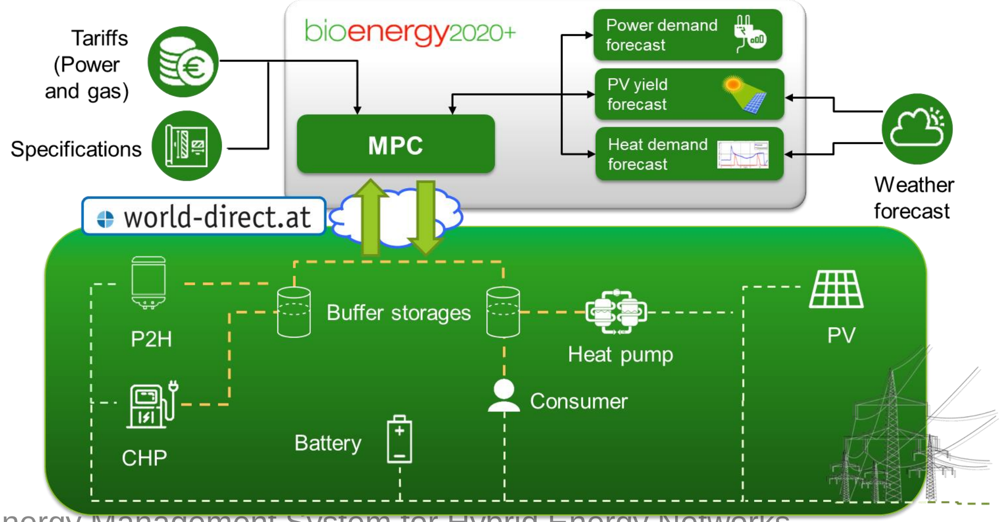
  - Two connected thermal storages, waste water heat pump, CHP, PV, P2H
  - Operational (+/-) since the beginning of the heating season 2019



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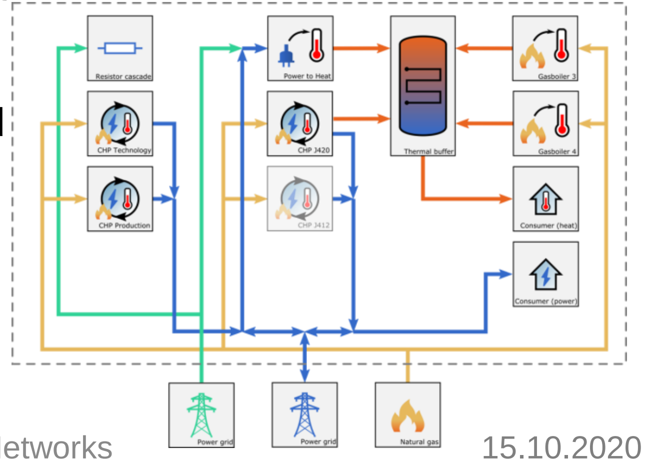
- **Production Facility Energy Management System**
  - Participation in the balancing energy market
  - Handling of uncertainties
  - Further implementations in pilot plants planned



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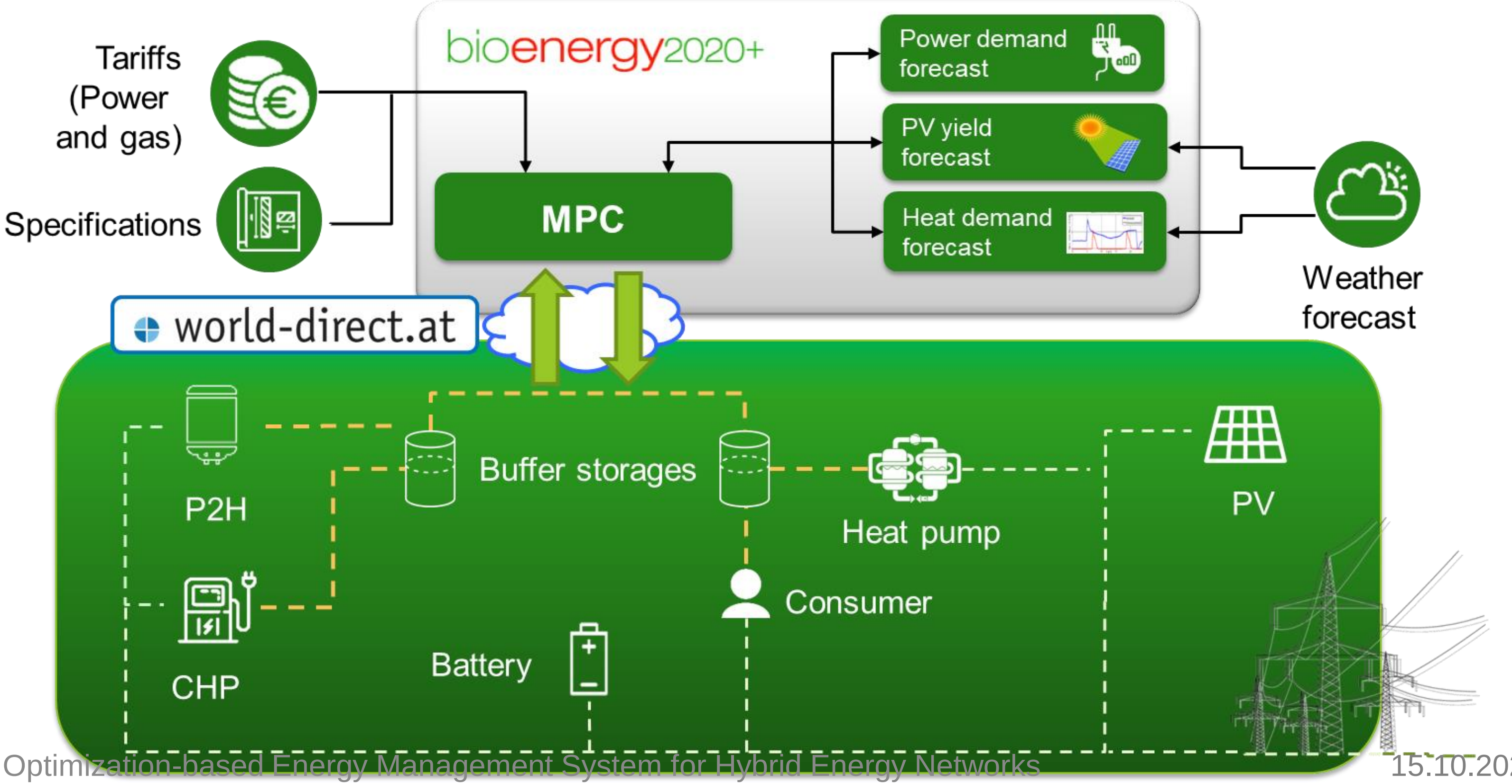
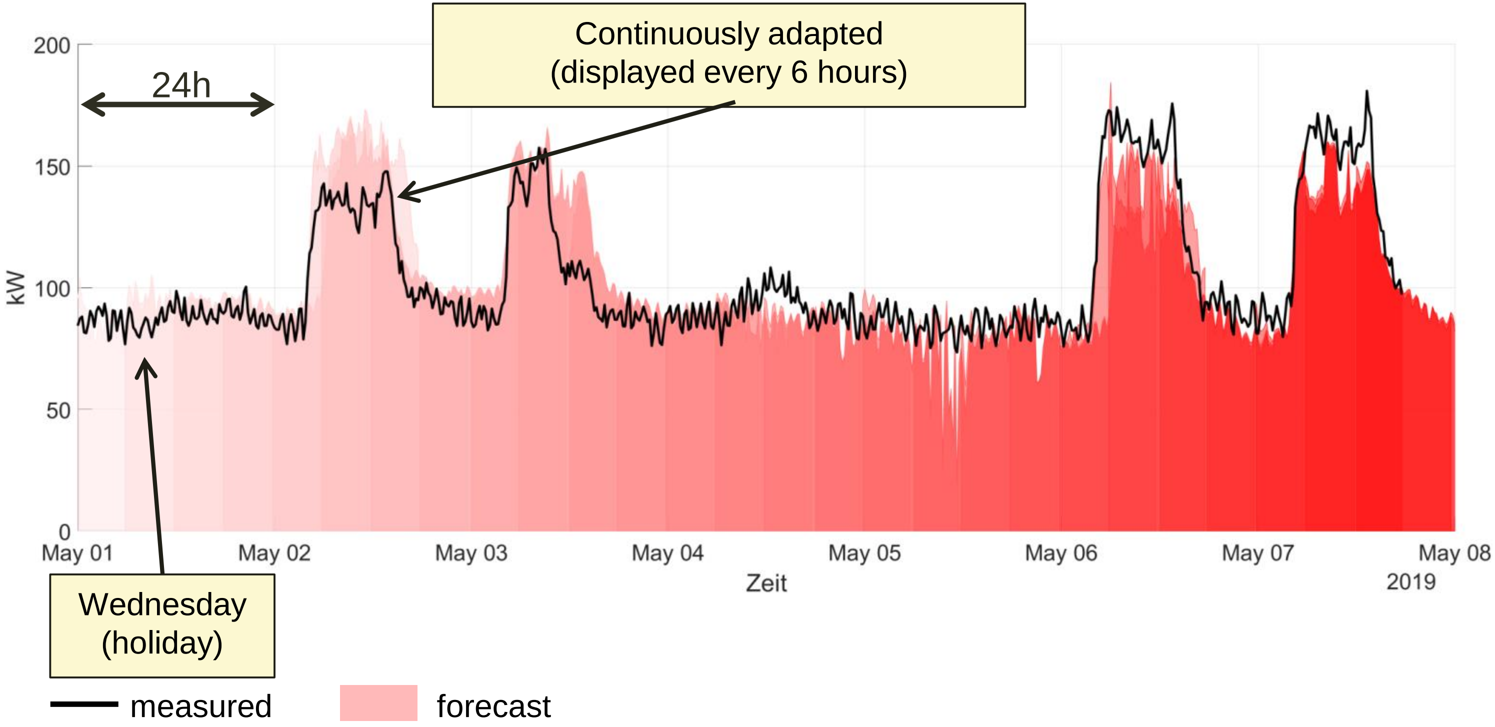
- **… and several others currently under development**
  - from family homes to food and agro industry

First Results: Building complex in Innsbruck (AUT)
Configuration

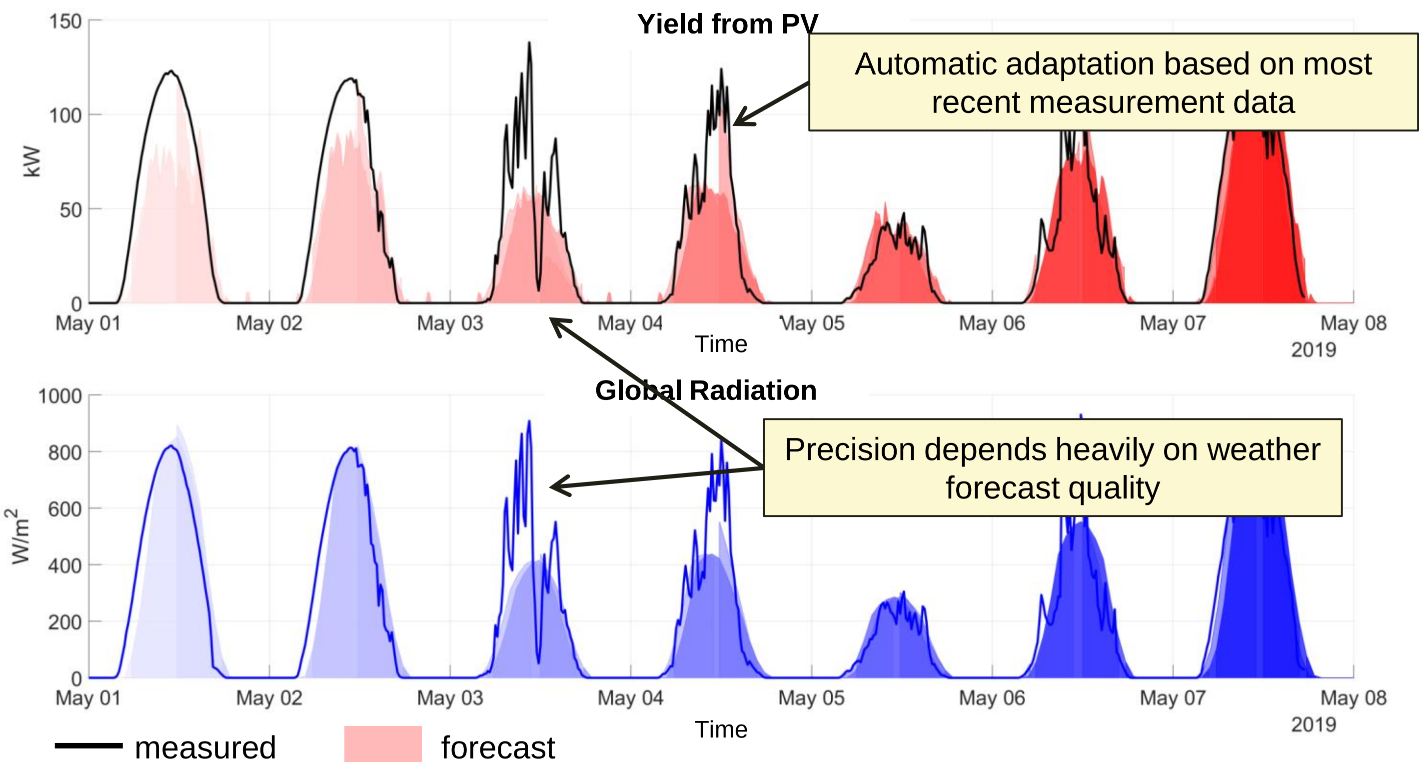


First Results: Building complex in Innsbruck (AUT)
Demand forecast – Electrical Power



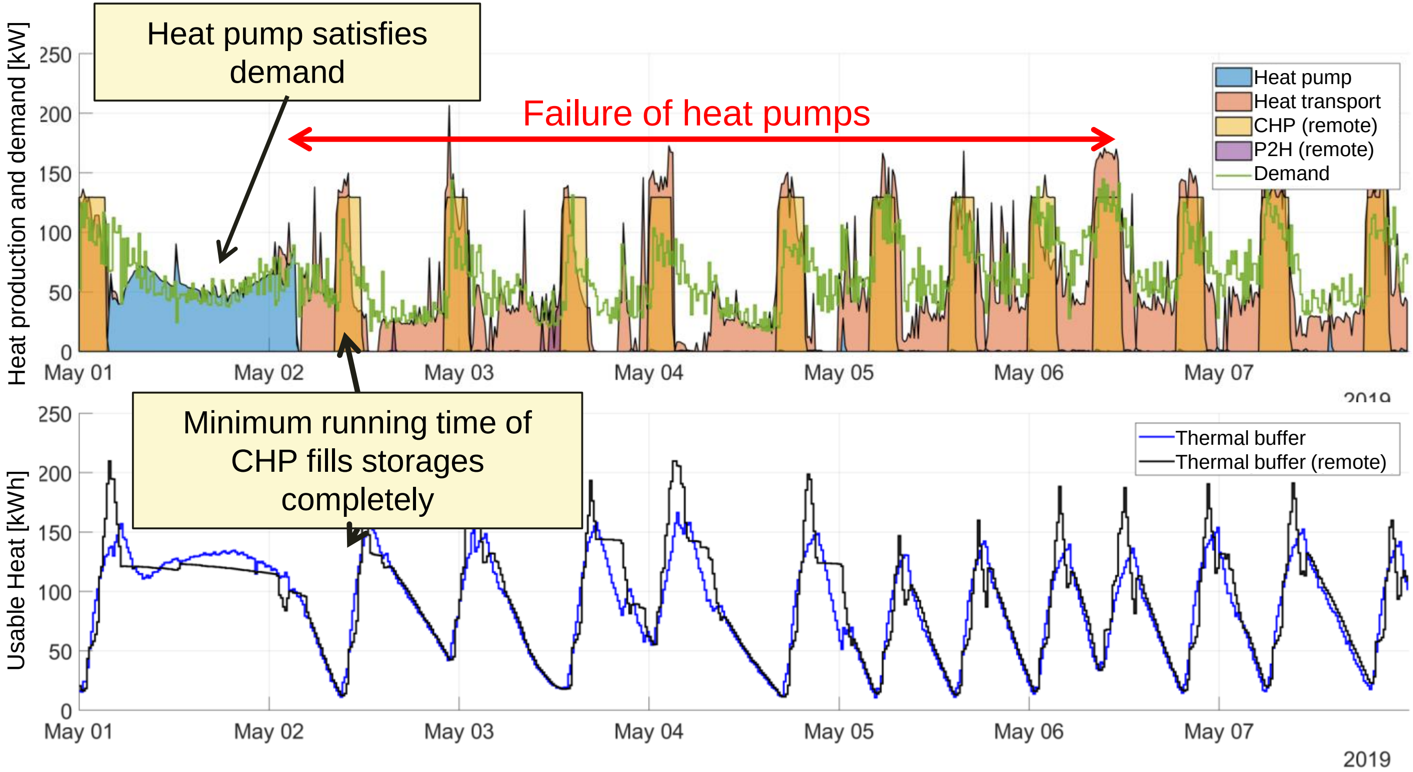
First Results: Building complex in Innsbruck (AUT)

Yield Forecast - Photovoltaics



First Results: Building complex in Innsbruck (AUT)

Control Strategy



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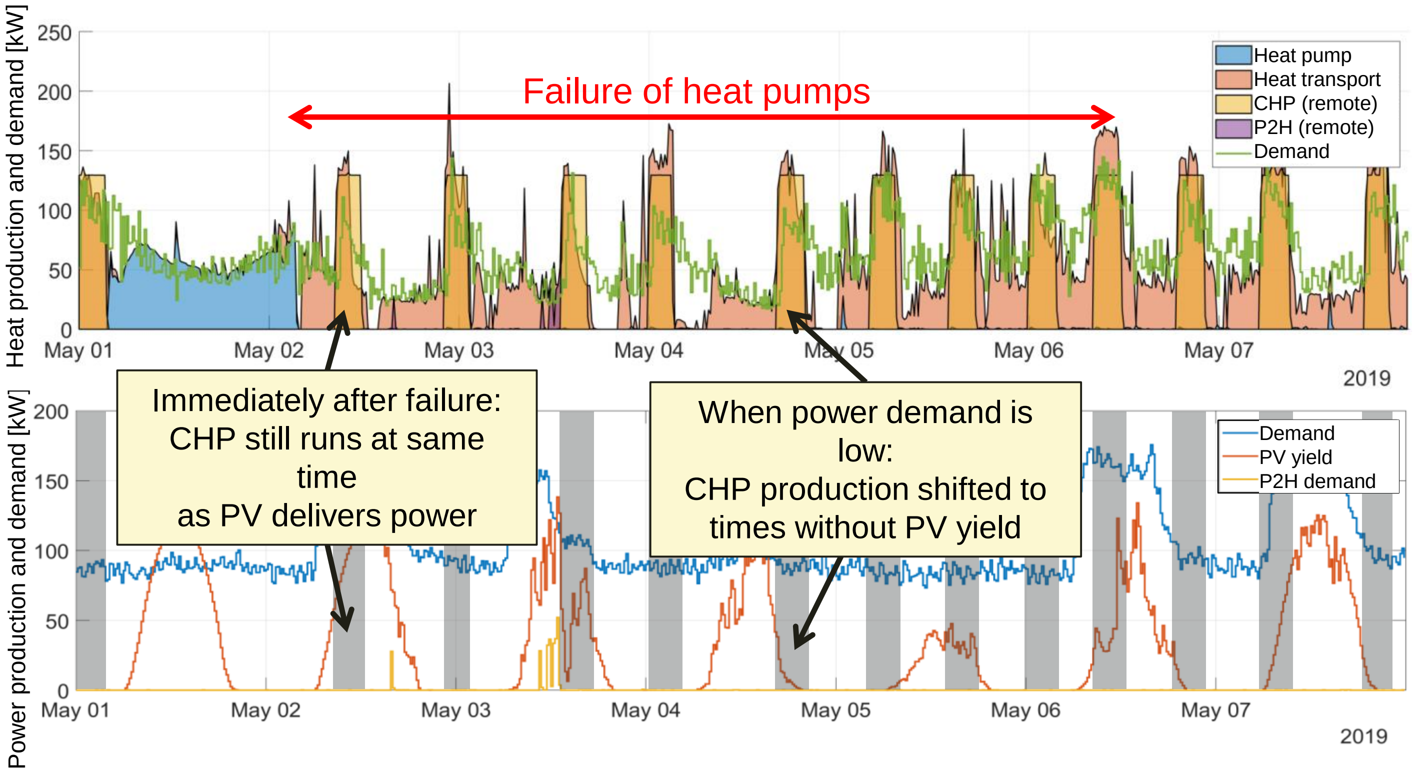
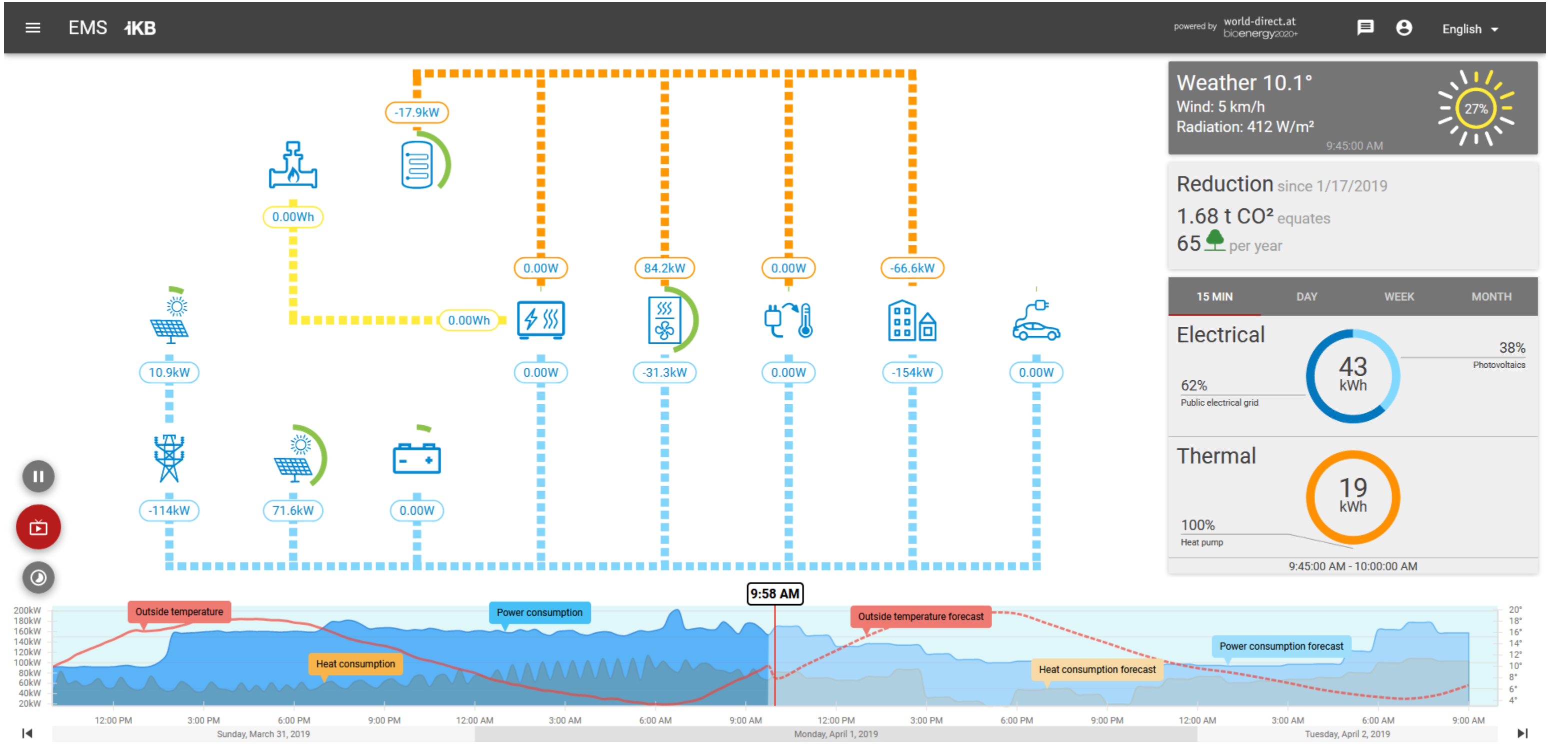


First Results: Demo @ IKB
Dashboard © World-Direct



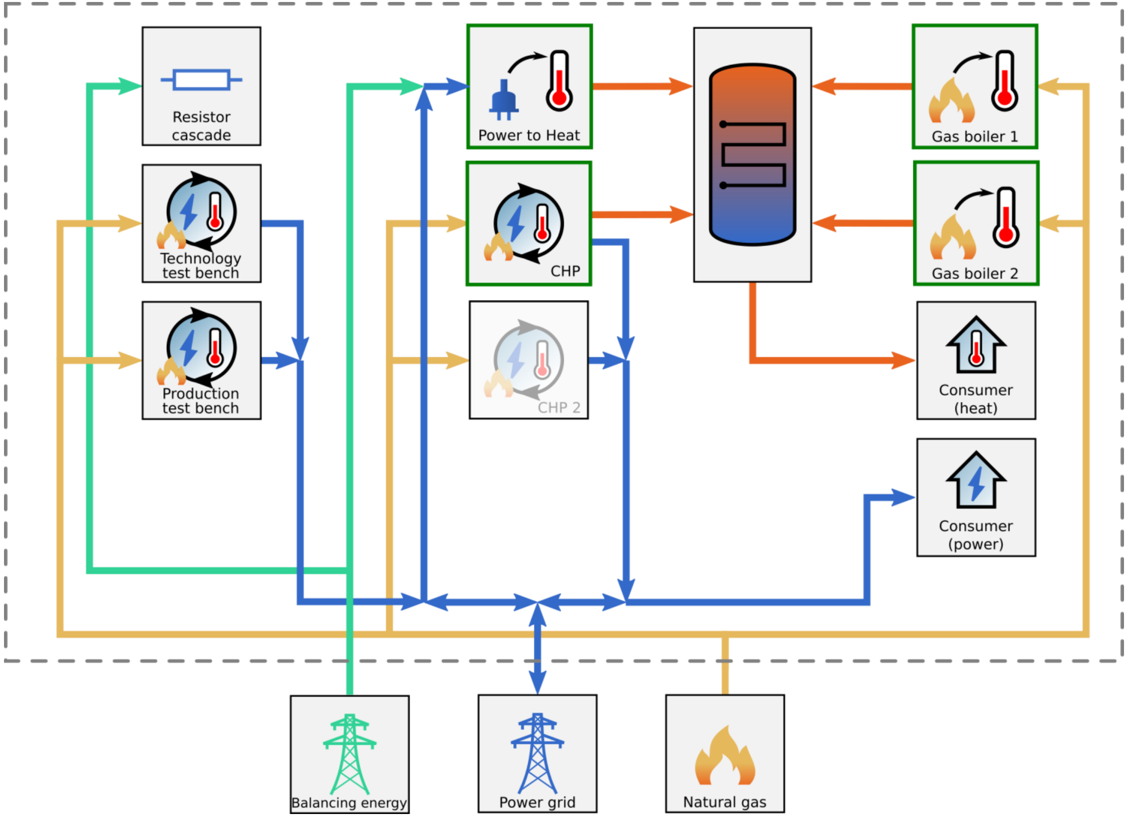
First Results: Demo @ IKB
Conclusions

- **Forecast** for PV yield, heat and power demand sufficiently accurate

- Thermal storages relatively small compared to production capacities
  - Many on/off cycles, long-term forecasts have little value
  - Could be improved by considering **heat storage capacity of buildings** and including building heat control in optimization
  - Buildings could act as „peak shavers“ and support heating grid

- Good performance of EMS for energy systems including heat requires **good low-level control concept**
  - Experienced HVAC planners, SCADA developers and PLC programmers should be part of the consortium

First Results: Factory for CHP units



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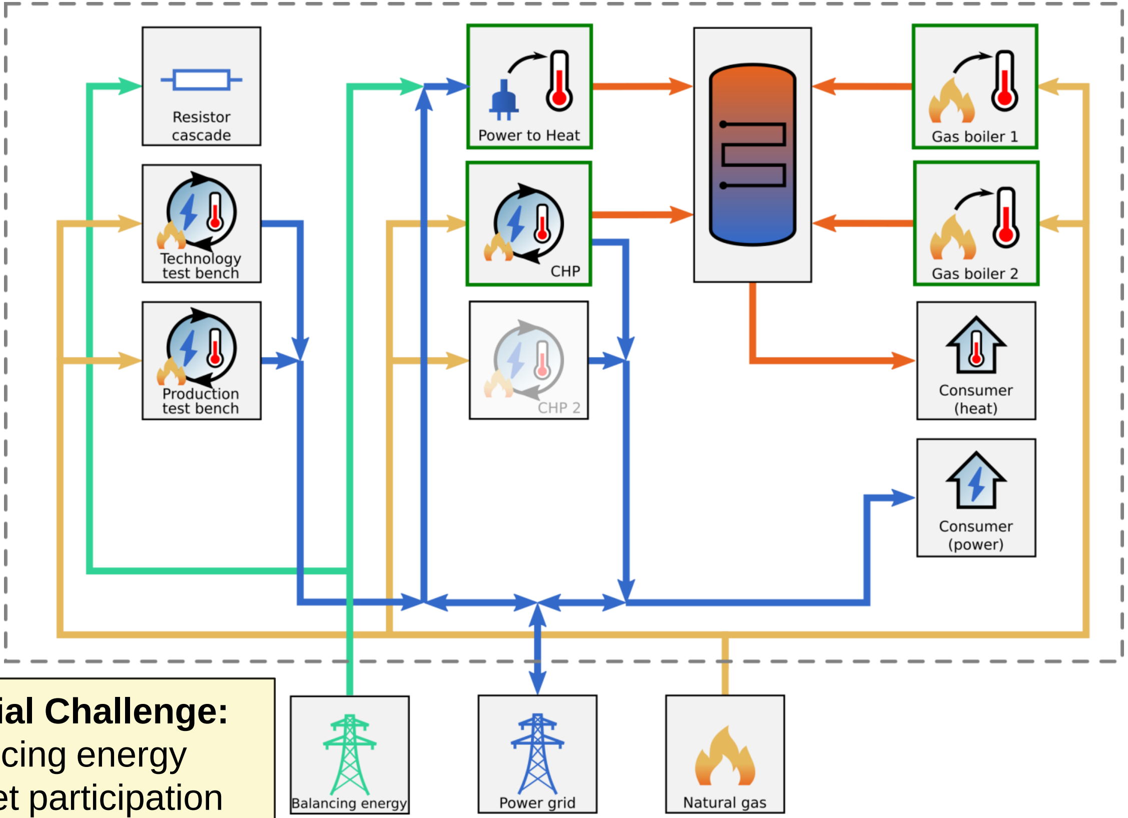
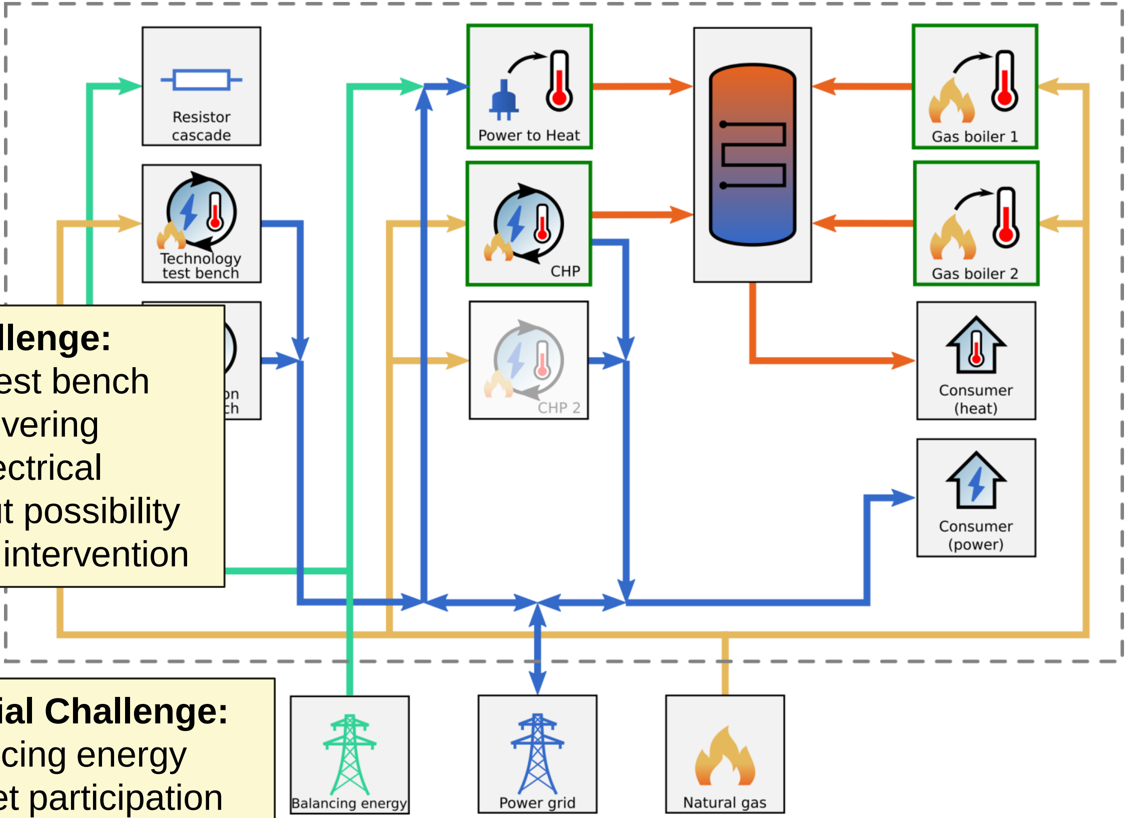


Special Challenge:
Balancing energy market participation

First Results: Factory for CHP units



Special Challenge:
Technology test bench suddenly delivering excessive electrical power without possibility of storage or intervention

Special Challenge:
Balancing energy market participation

First Results: Factory for CHP units

Solution:
- Stochastic Programming for handling uncertainty
- Markov Chain forecast method for generating switching scenarios

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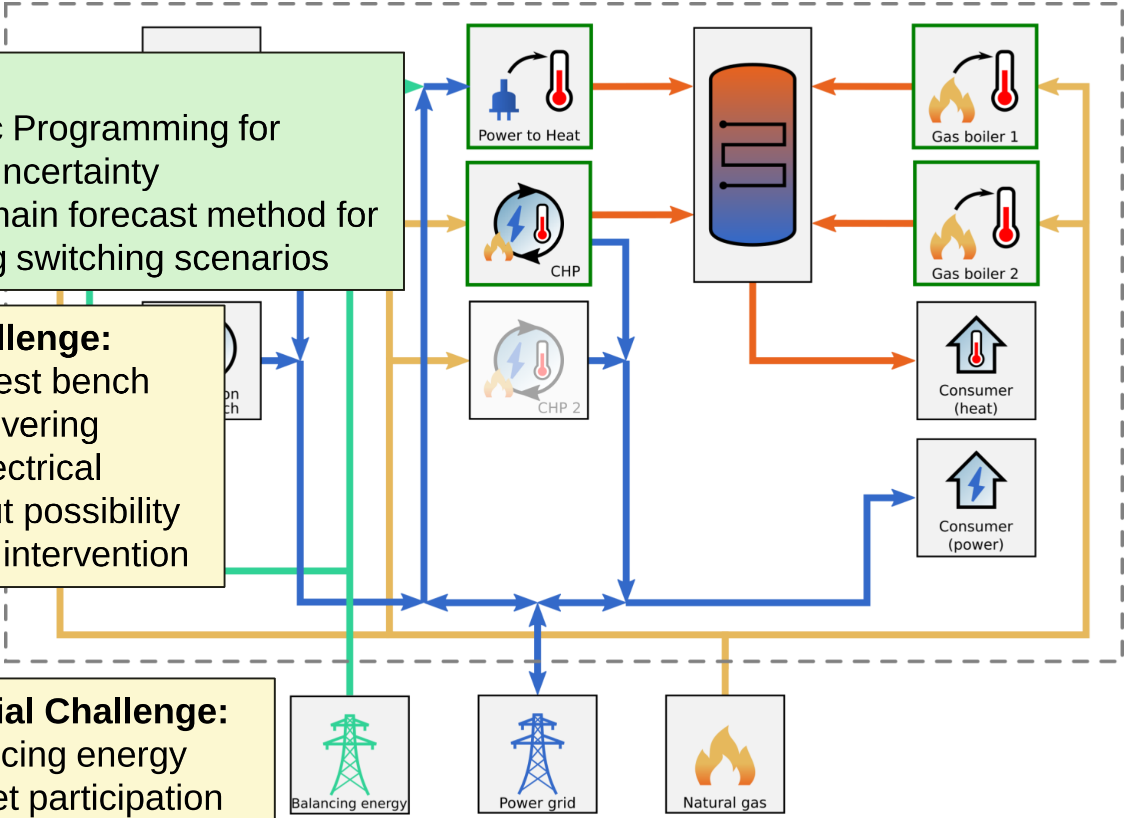
Technology test bench suddenly delivering excessive electrical power without possibility of storage or intervention



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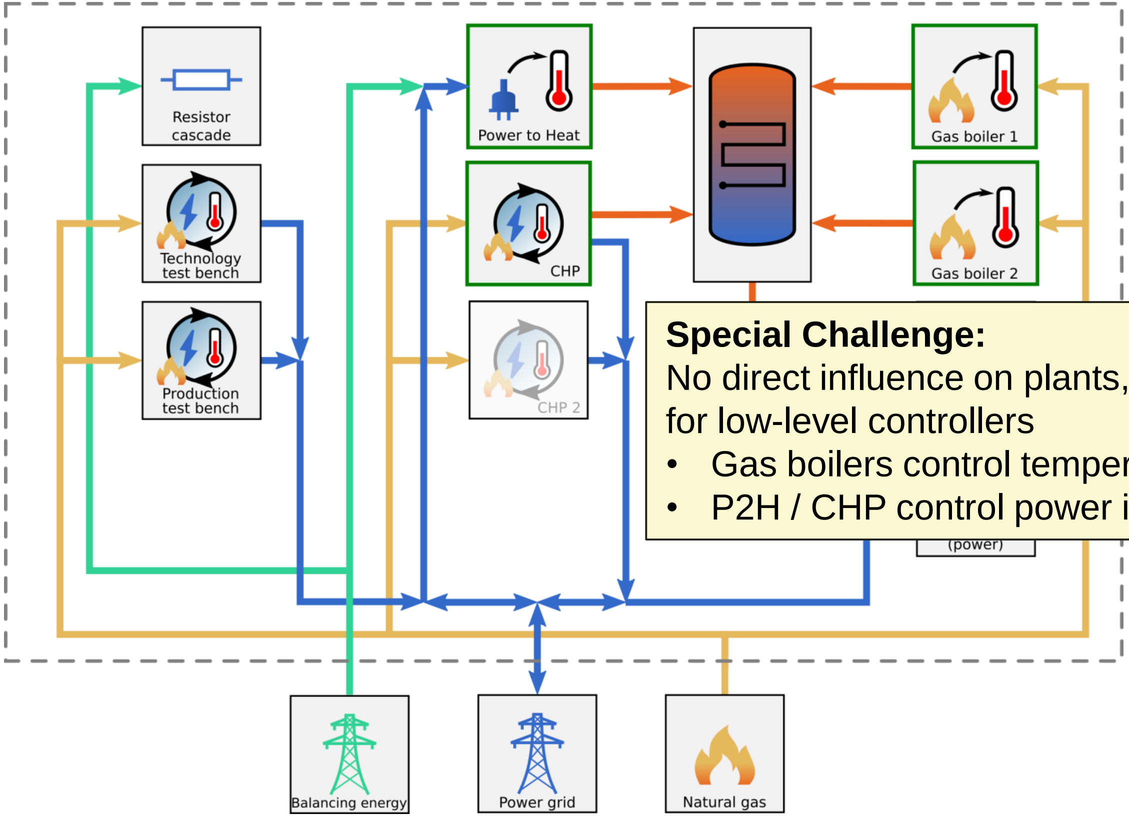
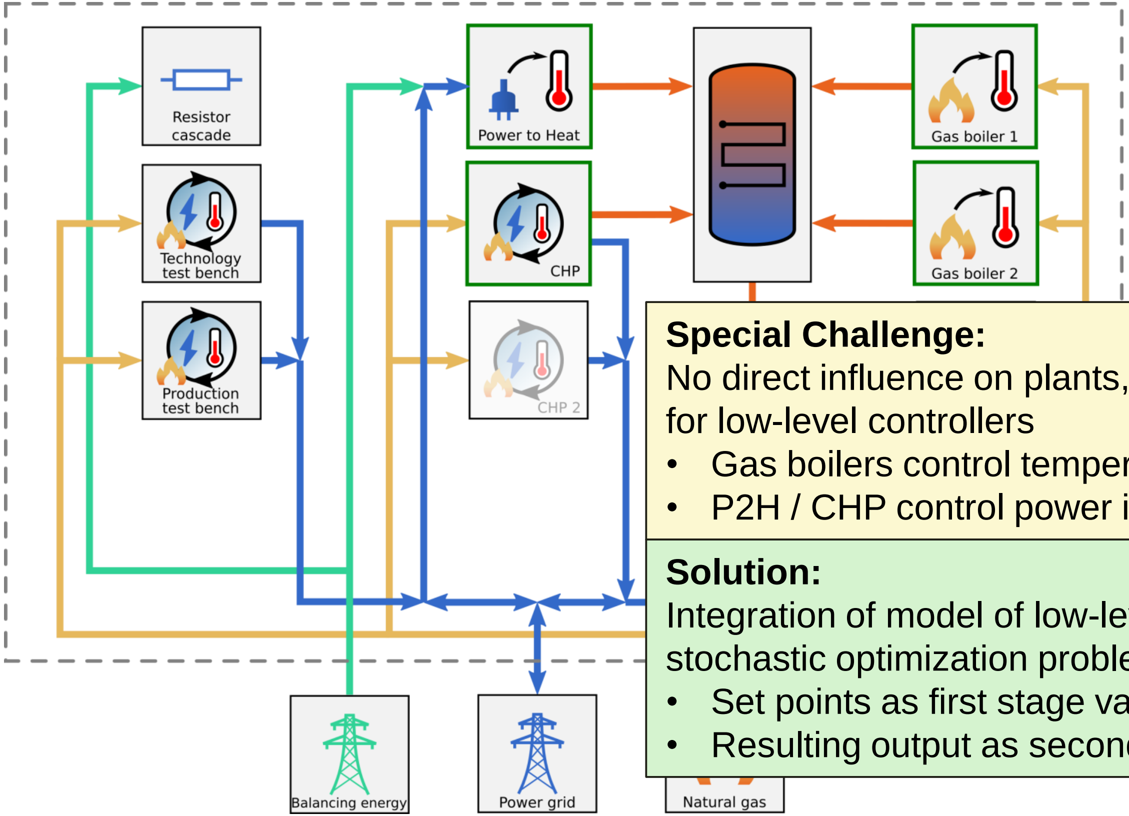


Special Challenge:
No direct influence on plants, only set points for low-level controllers
- Gas boilers control temperature in buffer
- P2H / CHP control power import/export

First Results: Factory for CHP units



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Solution:
Integration of model of low-level controller in stochastic optimization problem formulation

- Set points as first stage variables
- Resulting output as second stage variables

Implementation Challenges

- **Data, Data, Data**
  - The dependable supply with current data sampled at high frequency (< 15 min) is a challenge especially when retrofitting existing plants

- **Low-level controllers**
  - Thermal components often only support temperature control
  - Variable output levels are often not provided
  - Optimization interval is sometimes too long (esp. for electrical power)
  - EMS must provide setpoints for faster low-level controllers instead

- **Heat ≠ Power**
  - Existing control concepts were developed for microgrids = power grids
  - Varying temperature levels pose new challenges
  - Influence storage and transport capacities, COPs and efficiencies

Acceptance Challenges

- **Operators do not trust optimization**
  - Difficult to define and parametrize optimization problem that leads to solution that looks „right"
    - Some costs are real (fuel, power from grid)
    - Some costs are real, but difficult to get right (start/stop costs)
    - Some costs are fictional („soft constraints")
  - Always start with a **decision support** system
    - Only then „close the loop"
- **Safety First**
  - Always insist on fail-safe fall-back operating strategy
  - Always define criteria when to fall back to fall-back solution

Conclusion & Outlook

- The **complexity** of cross-sectoral / hybrid energy systems calls for support by computers and algorithms
- **Modularity** enables quick implementation of future multi-energy system **planning** and **operation** tasks
- **Data-driven approaches** enable additional benefits
  - Monitoring, predictive maintenance, fault detection
- **Ongoing Research**
  - Technology flexibilization through controller interaction
  - Demand side management
  - Varying temperature levels

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