INTELLIGENT ENERGY MANAGEMENT

Intelligent Energy Systems / Energy Technologies

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Fraunhofer IISB

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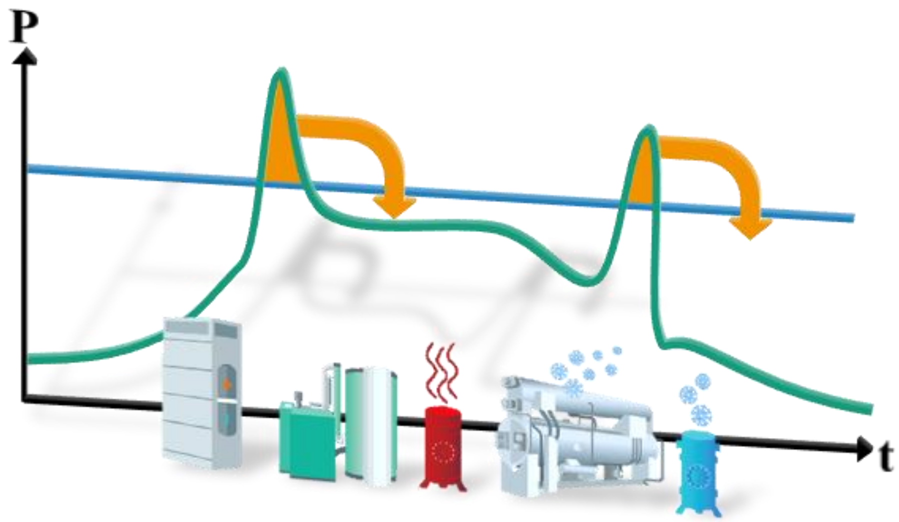
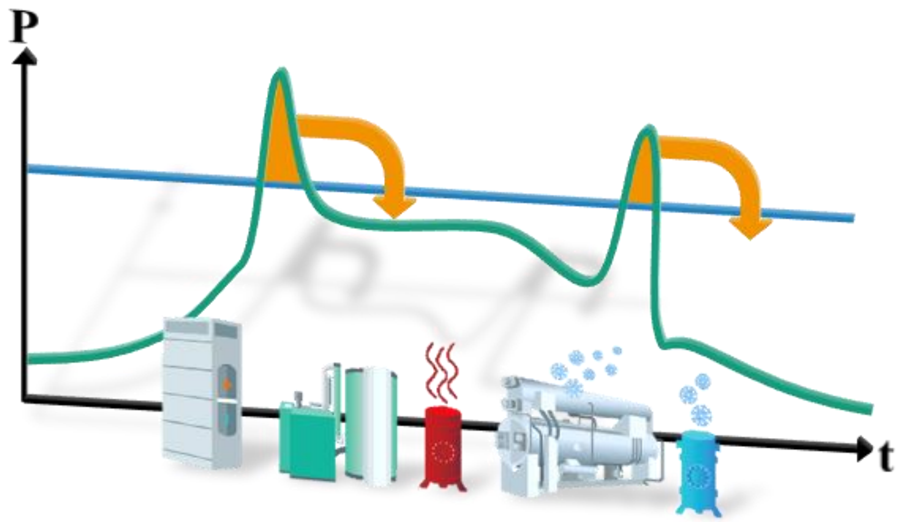
CONTENT

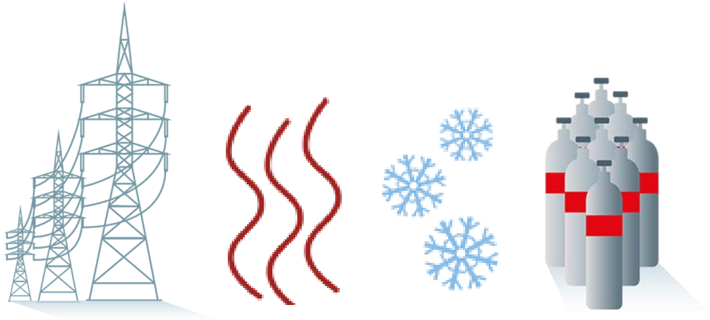


MOTIVATION



Motivation

- Typical energy infrastructures in industry consists of different energy sectors
  - Electrical (AC und DC)
  - Heating and Cooling
  - Gas (e.g., natural gas, hydrogen)
  - Other (e.g., compressed air, vacuum etc.)



  → The sectors are coupled via different plants (e.g., heat pump, CHP, chiller)

- Intelligent energy management → Consideration of all **relevant couplings** between the components and combination of different **intelligent operational strategies**
  - Peak shaving
  - Efficiency increase
  - Self-consumption optimization

Main goals:
Reduction of CO_2 emissions and energy costs

cf. [IISB19]

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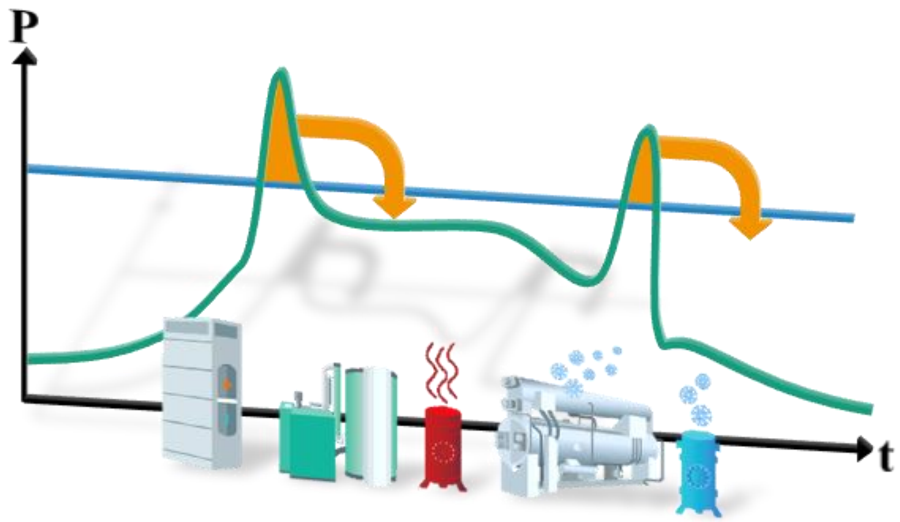
BASICS

- Motivation ▶
- Basics ▶
- Real-world laboratory ▶
- Energy system optimization ▶
- TotalSystemControl ▶
- Summary ▶
- Publications ▶
- Contact ▶



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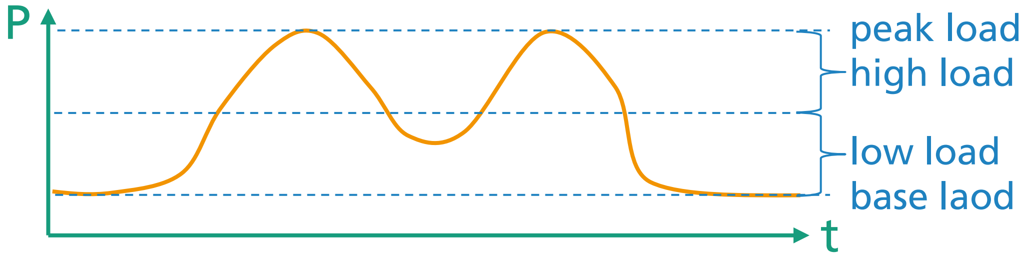
Basics
Load profiles

- Load profile: time course of the purchased electrical power, other name: load curve
- Load profiles are composed of
  - **Base load**: Purchase that is always present, depending on seasonal and calendar variables.
  - **Peak load**: Short-term high purchase that differs significantly from the base load

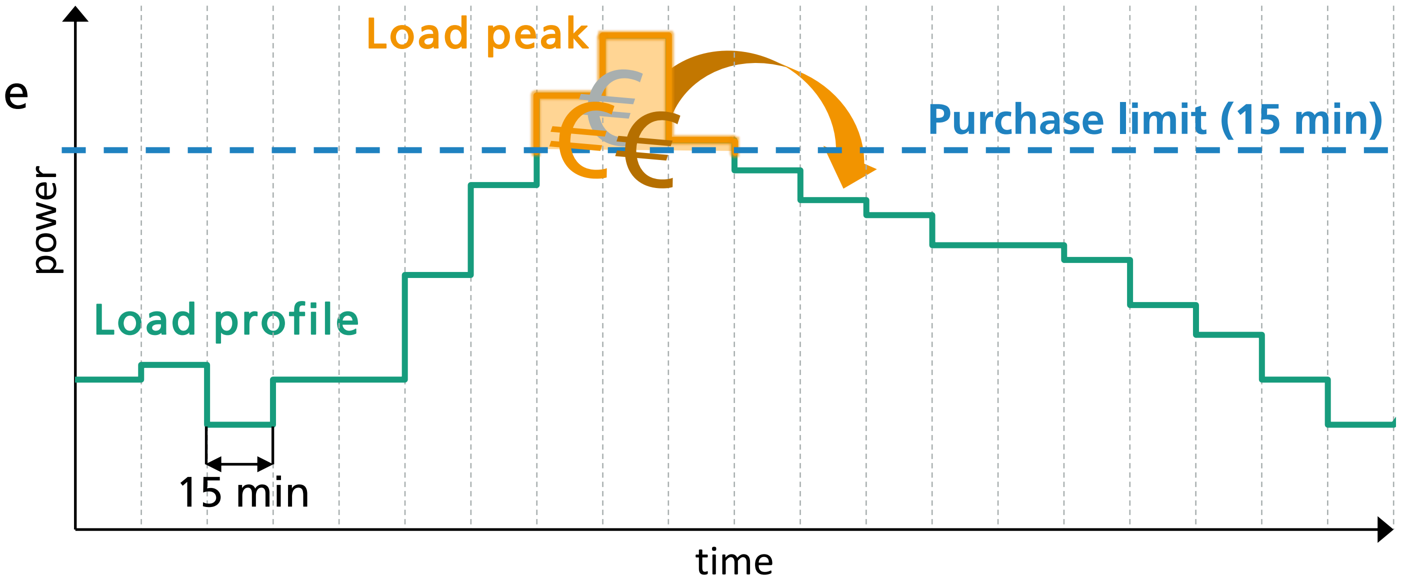


  - **Low load**: Purchase, which is closer to the base load than to the peak load
  - **High load**: Purchase, which is closer to the peak load than to the base load
  - There are different definitions in literature, e.g.:
    J. L. Mathieu, P. N. Price, S. Kiliccote et al. „Quantifying Changes in Building Electricity Use, With Application to Demand Response“. IEEE Transactions on Smart Grid 2.3 (2011), S. 507–518. DOI: 10.1109/TSG.2011.2145010.

Basics
Peak shaving

- Initial situation: Load profile with the 15 min mean values of the power purchased from the energy supplier
- Definition of a **purchase limit** (maximum allowed mean power per 15 min period)
  - Limit can be constant or time variable
  - Load peak becomes visible
- **Highest load peak** in the billing period is relevant for electricity costs
  - Maximum 15 min average value should be reduced to purchase limit
  - 1 min values may exceed this

Load profile with 15 min mean values



cf. [Lan20], [Lan21a]

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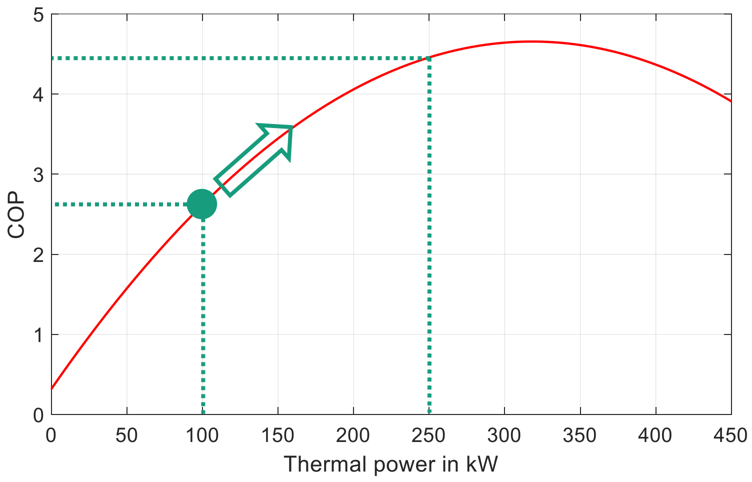
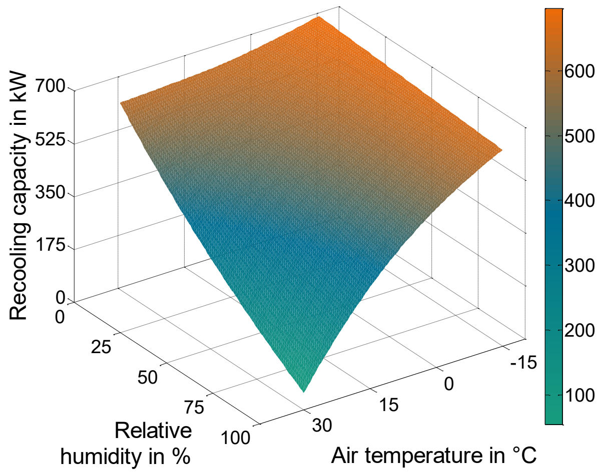
Basics
Efficiency increase

- Shift operation points to time periods with higher efficiency → energy storages needed
- Example: Chiller and recooling plant
  - **Chiller**'s efficiency (COP*) depends on thermal power
  - **Recooling plant**'s efficiency depends on ambient temperature and relative humidity



COP* of chiller based on cooling load

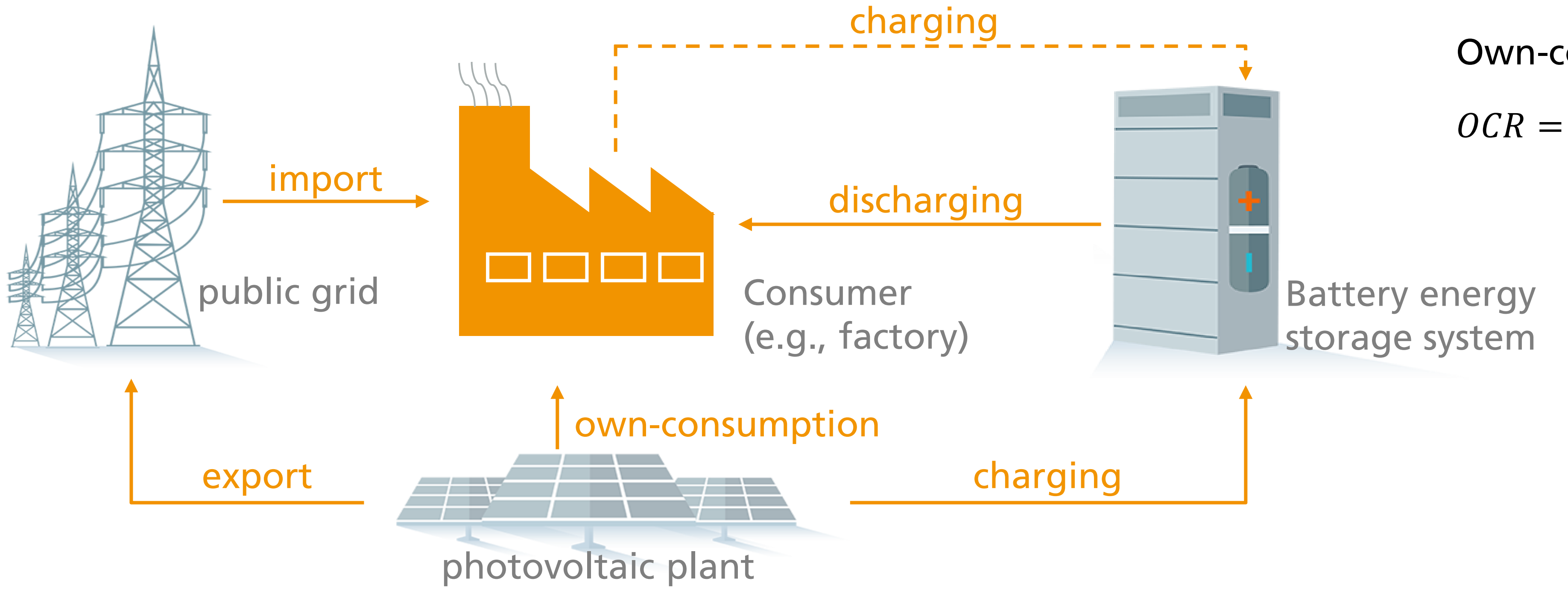


Cooling capacity of recooling plant based on ambient temperature and relative humidity

*coefficient of performance: COP = Q_{th} / P_{el} cf. [Pul19a], [Pul19b]

Basics
Self-consumption optimization

- Optimization of self-consumption (e.g., energy of RES*)
  - Charge storage, if surplus locally generated energy is available
  - Discharge storage, if demand exceeds production



KPIs

Self-supply rate SSR:

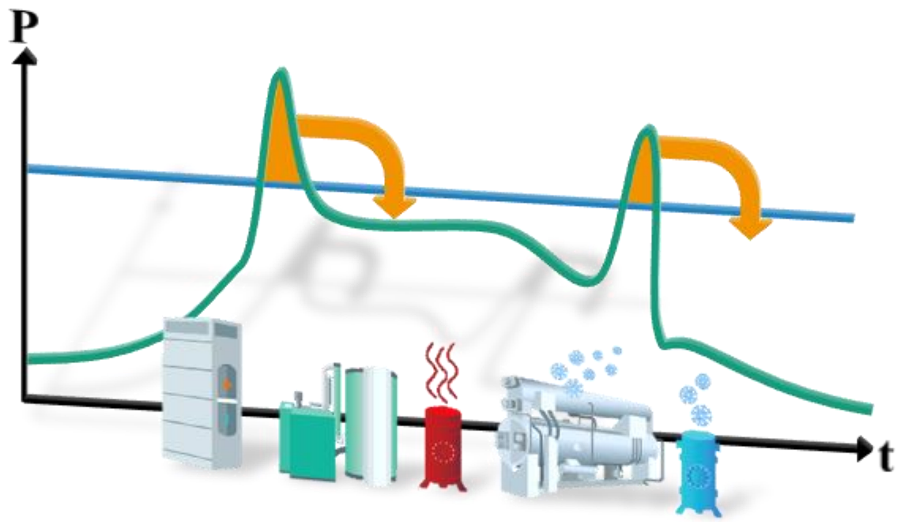
$$SSR = 1 - \frac{E_{import}}{E_{demand}}$$

Own-consumption rate OCR

$$OCR = 1 - \frac{E_{export}}{E_{generation}}$$

*renewable energy sources

REAL-WORLD LAB



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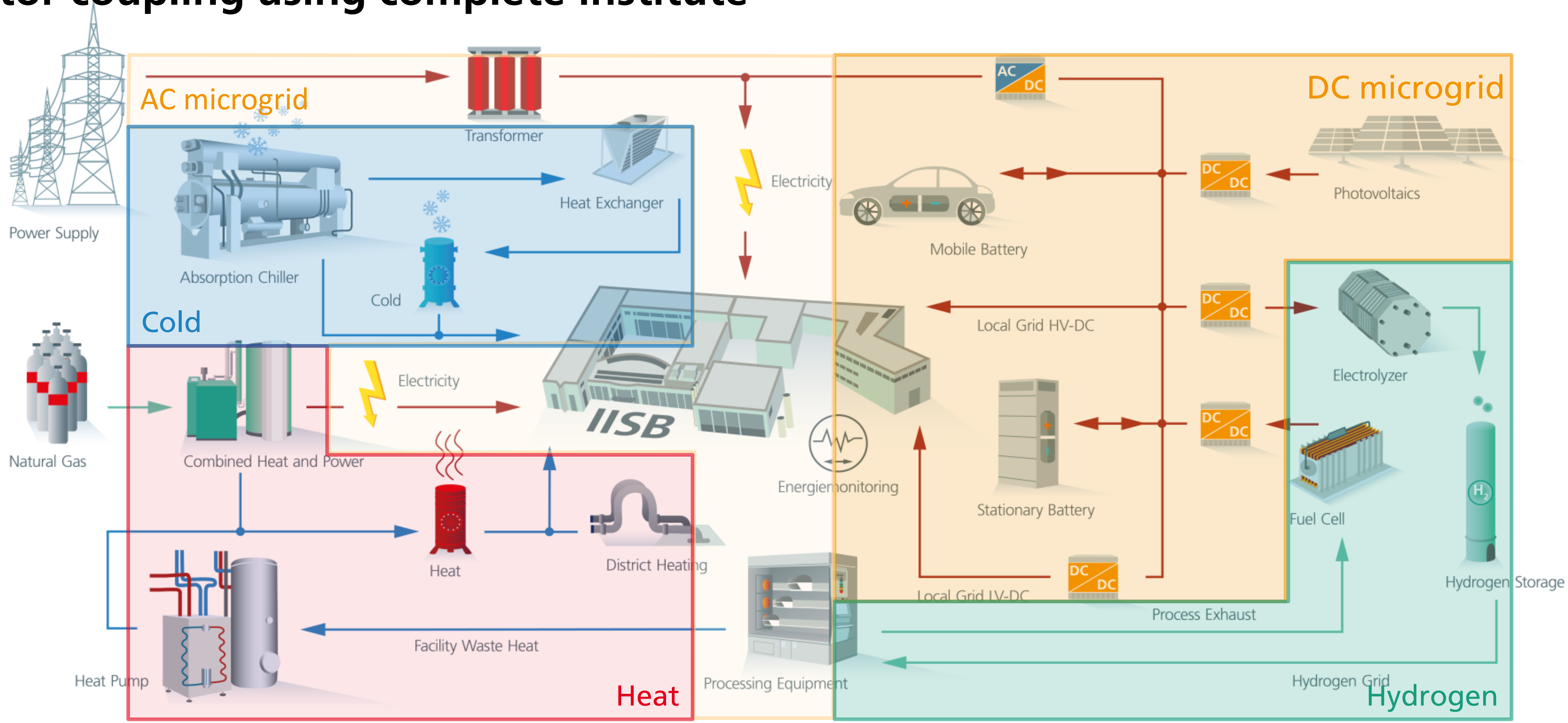
Real-world lab at Fraunhofer IISB as research and demonstration platform for sector coupling using complete institute



cf. [Och19], [Mar19]

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Real-world lab at Fraunhofer IISB
Energy storages

- Energy storage systems at Fraunhofer IISB
  - Electrical energy storages (stationary and mobile Lithium-Ion, Redox-Flow)
  - Thermal energy storages (hot- and cold-water storages)
  - Hydrogen storages (pressure, chemical)

Redox-flow container with IISB's control system

Hot water storages

Cold water storage

Mobile Lithium-Ion Battery

Chemical hydrogen storage system based on LOHC

cf. [Och19], [Mar19]

Real-world lab at Fraunhofer IISB
CPH, heat pump and cold storage

- Application CHP* combined with heat storage
  - Increase of energy self-generation (heating, electrical power)
  - Utilization for peak shaving with algorithms and control developed at IISB
- Application heat pump
  - Utilization of residual heat in exhaust air systems
  - Load shedding during electrical load peaks
- Application cold storage
  - Increasing efficiency
  - Increase of utilization of free cooling
  - Peak load reduction

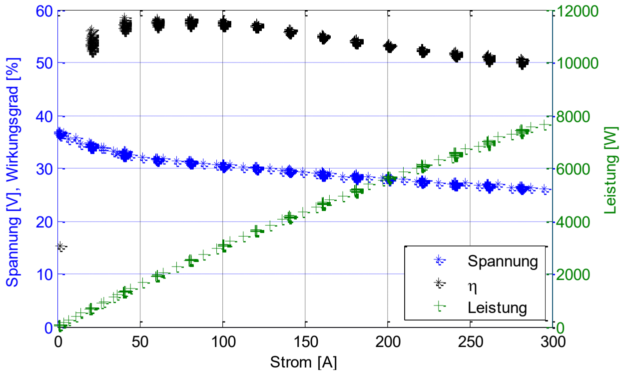
*combined heat and power plant

cf. [Lan21b], [Mar19]

Real-world lab at Fraunhofer IISB
Hydrogen technology – system integration

- Fuel cell, electrolyzer, hydrogen storage
  - Development and investigation of hydrogen systems
  - Characterization of fuel cells and electrolyzers
  - Development of component models and simulations
  - Model based development of operational strategies

Hydrogen test bench:
Gas mixture and conditionings system



Measurement data of a fuel cell experiment

LOHC container for investigation on long-term storage of electrical energy

cf. [Ste18]

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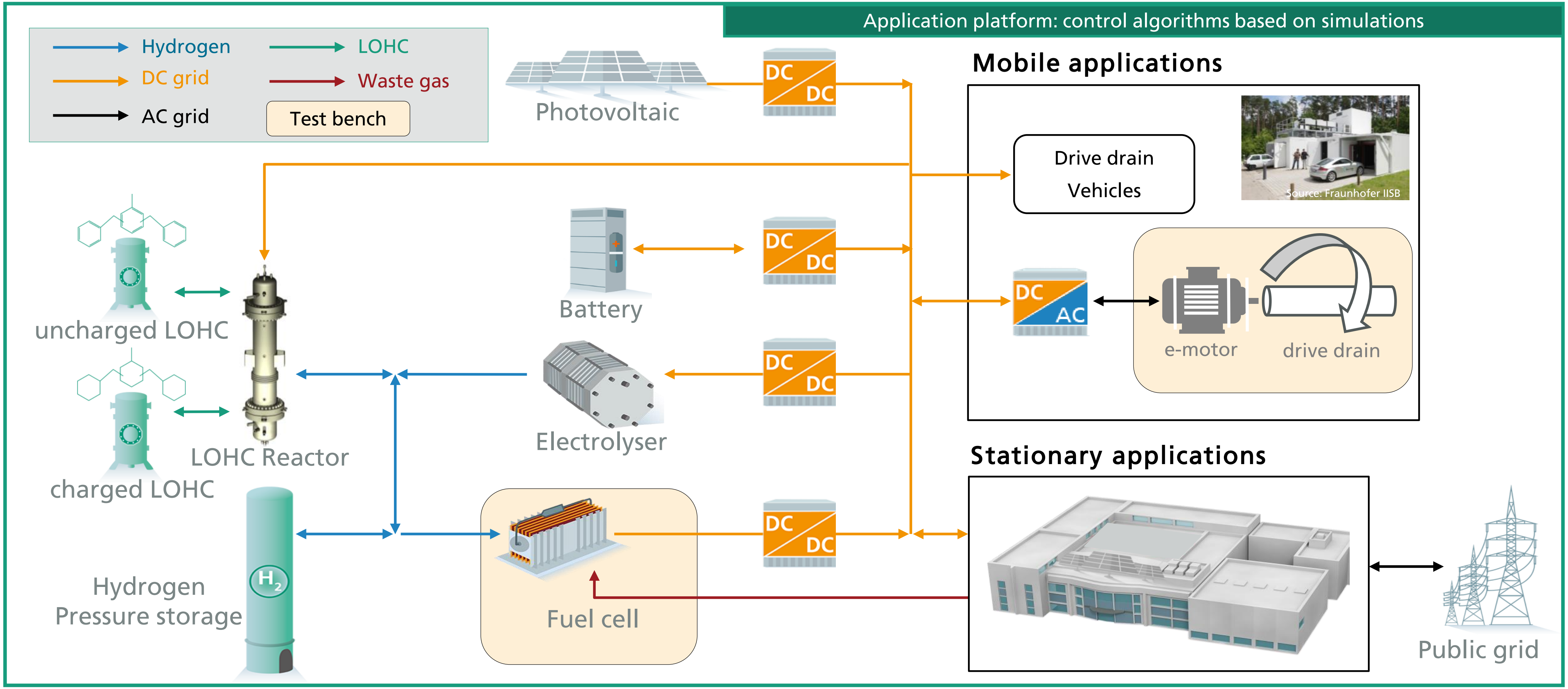
Real-world lab at Fraunhofer IISB
Application platform for hydrogen



cf. [Gei21]

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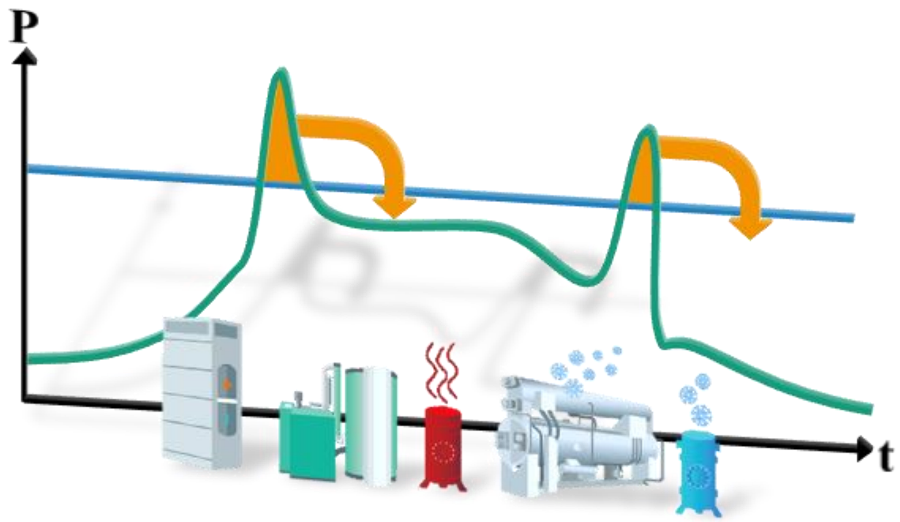
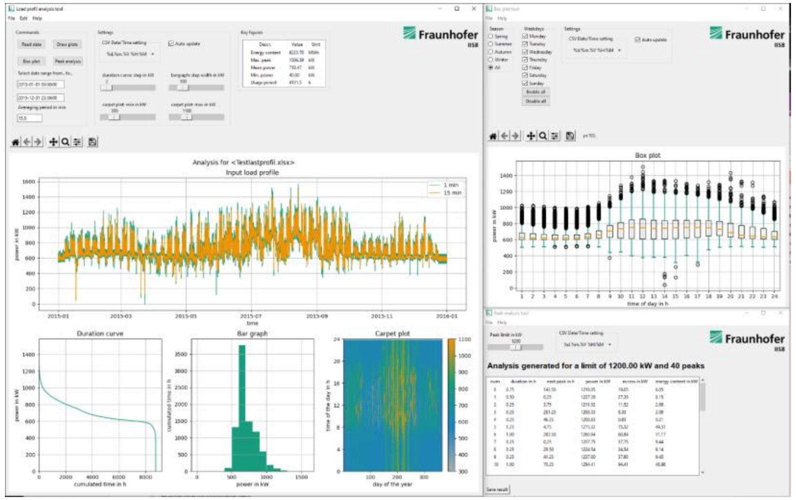
ENERGY SYSTEM OPTIMIZATION



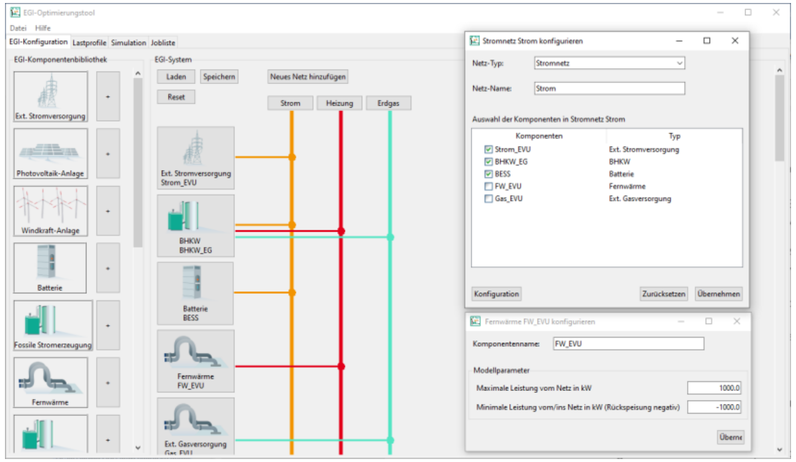
Energy system optimization
Simulation

- Advanced energy system simulation
  - Data analysis methods and tools
  - Model library for energy-related plants and components, e.g., energy storages, generators like heat pump, chiller, CHP, PV, aqua-thermal plant etc.
  - Dimensioning algorithms for applications like peak shaving and increase of self-supply etc.
- → Non-invasive optimization of energy systems considering all relevant energy sectors
- → Scenario-based study of adjustments and extensions

Free Loadprofile-Analysis-Tool, available online: https://www.proenergie-bayern.de/de/veroeffentlichungen.html



Simulation tool for the energy building infrastructure based on a component library as well as intelligent operational strategies (project: ProEnergie – Bayern)



cf. https://www.energy-seeds.org/

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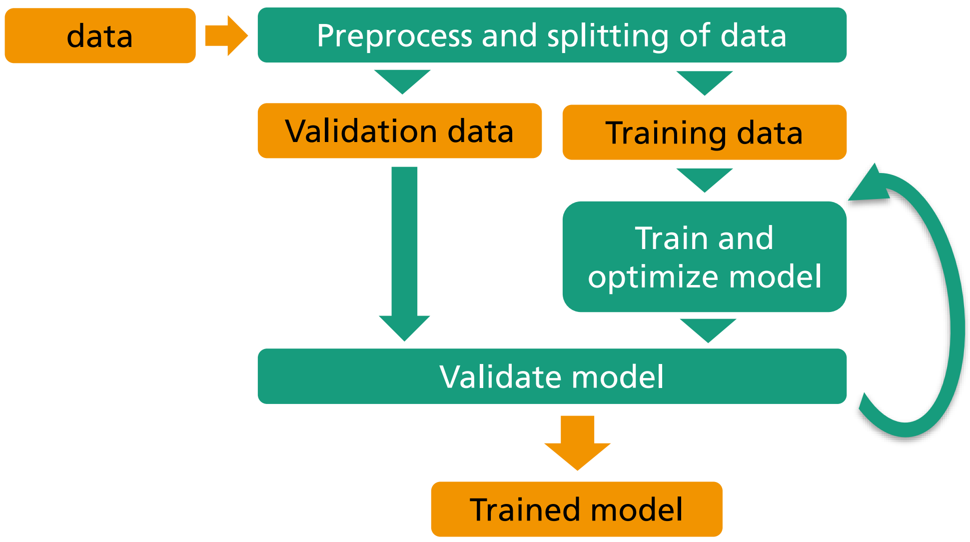
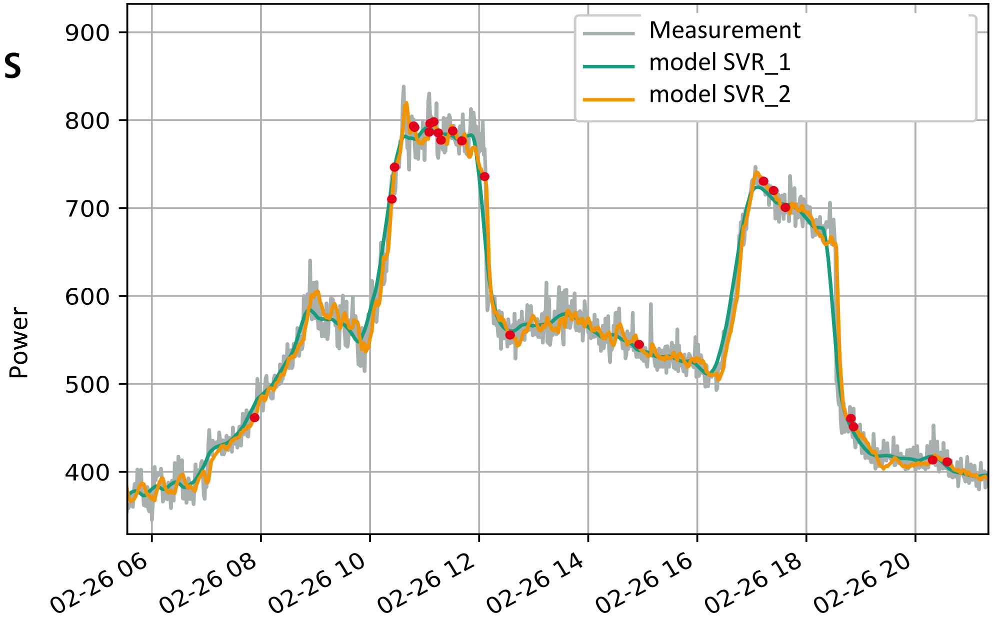
Energy system optimization
Data-based modelling of energy system components

- Model library for energy system components
- Data-based approach and use of AI
- Training of model with historical measurement data
- Automated process for easy transfer to other applications





Comparison of measurement and two distinct models

cf. https://www.energy-seeds.org/

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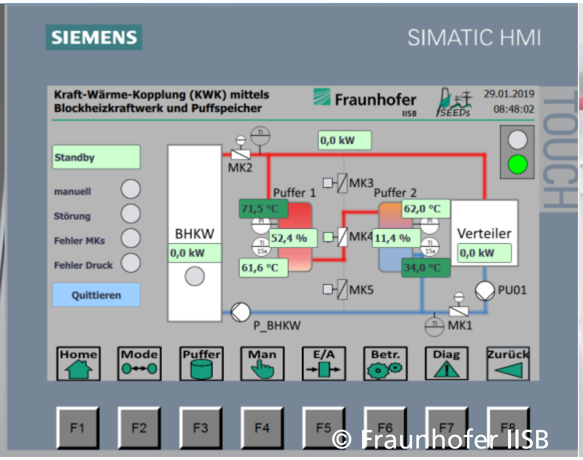
Energy system optimization
Automation

- Implementation of innovative plant concepts for energy systems
  - Realization of demonstrators and prototypes
  - Implementation of control and measurement functions according to IEC 61131
  - Plant characterization and functionality validation

Heat pump system for heat recovery from exhaust air



Overview screen for visualization of a CHP plant (HMI)

Efficient connection to cooling network via transmission station

Large cold storage as intelligent component in the cooling network

cf. https://www.energy-seeds.org/

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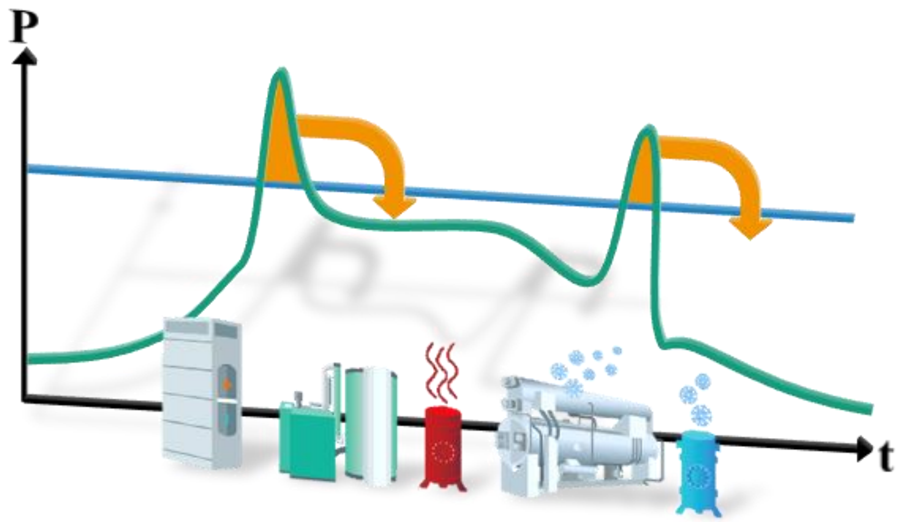
TOSYCO



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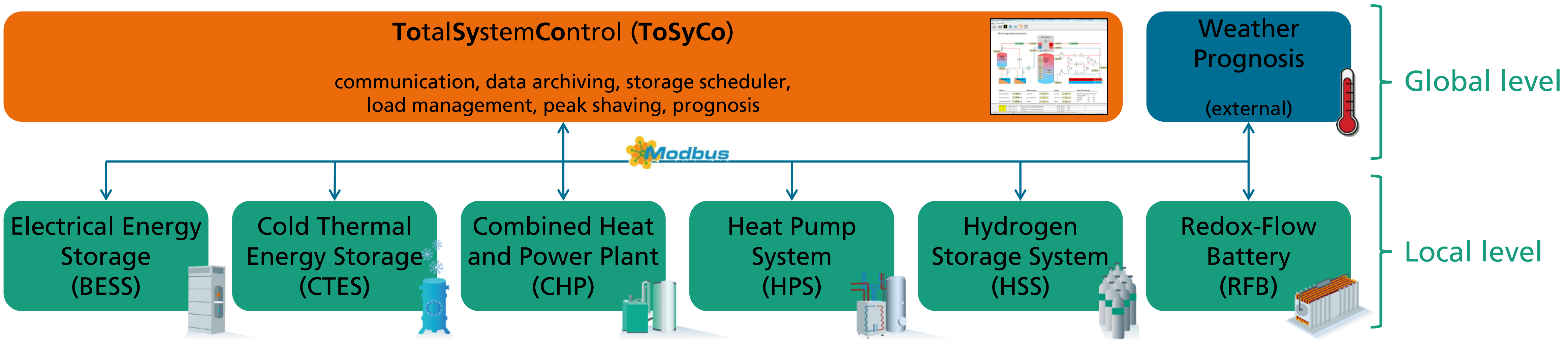
Framework for an intelligent energy management system (iEMS)



Global level
- ✓ Load prognosis
- ✓ Superior operating strategy
- ✓ Schedules for storage operation
- ✓ Peak shaving

Local level (PLC*)
- ✓ Safety functions
- ✓ Basic functionality, autonomous operational strategy
- ✓ Physical inputs and outputs
- ✓ Operating unit for the plant

*programmable logic controller

cf. [Lan19]

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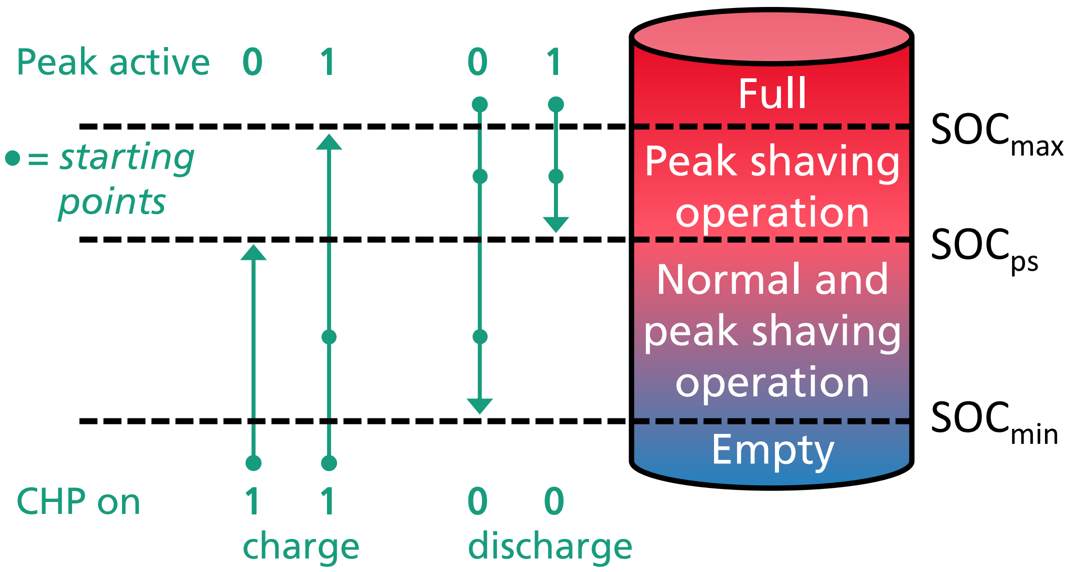
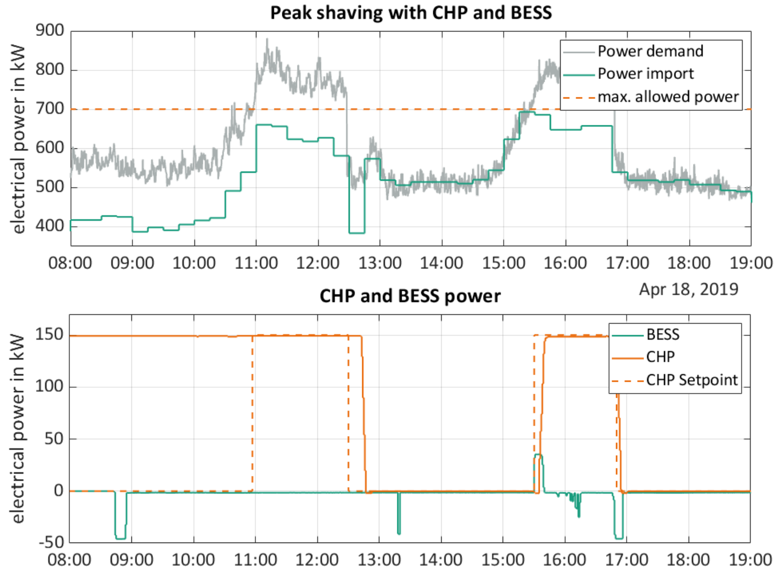
TotalSystemControl
Operational strategies

- Example: Extension of a heat/electricity-controlled CHP unit to include peak shaving functionality
  - Division of the thermal energy storage into four virtual zones, reserved zone for peak shaving
  - Intelligent operational strategy (including FSM) for retrofitting existing CHP systems
  - Battery system for increasing the dynamics (e.g., start-up process of the CHP)





Measurement result for peak shaving with CHP and battery. 18 % reduction of peak

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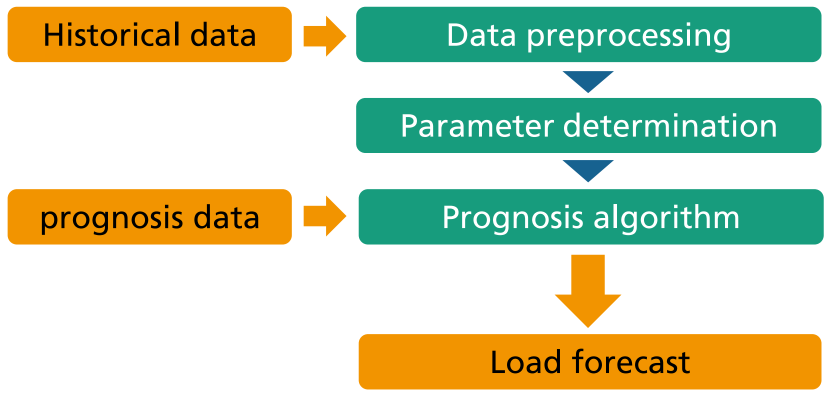
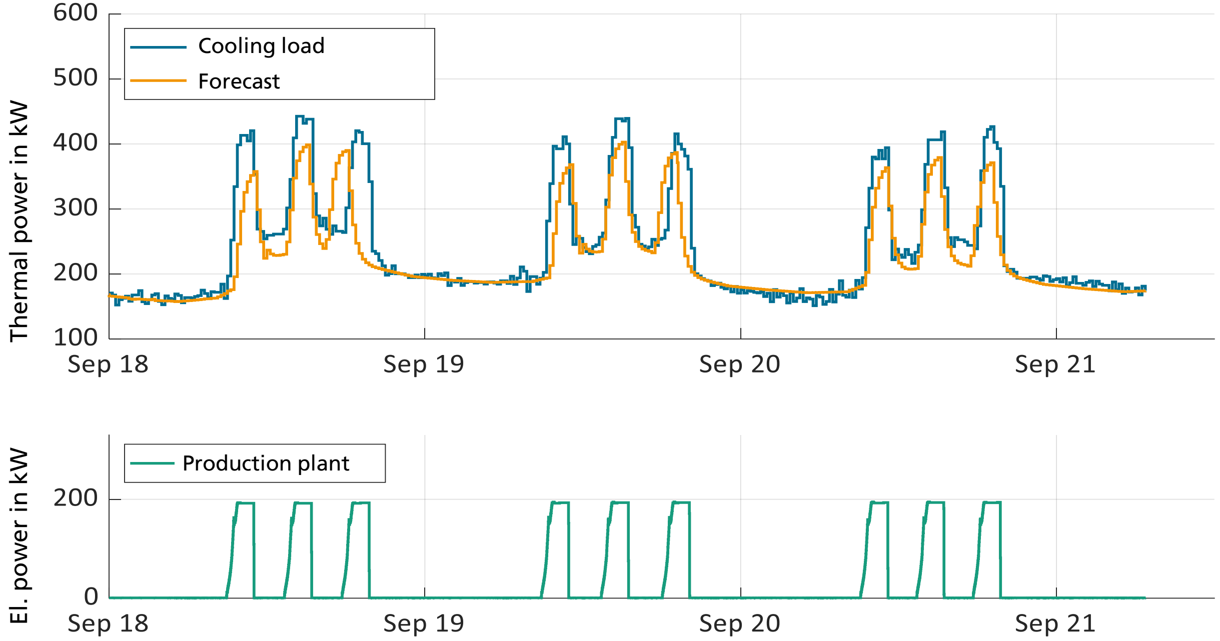
*finite state machine

cf. [Lan21a]

TotalSystemControl
Load forecasting



- Methods
  - Time series models (ARIMA)
  - Artificial Neural Networks
  - Machine learning algorithms
- Standalone implementation
- Automated process
- Integration in predictive control algorithms
- Accuracy:
  - Electrical load: MAPE 5%
  - Thermal load: MAPE 10 %



Forecast of cooling load (top), which is strongly shaped by the operation of a production plant (bottom)

cf. [Mar19]

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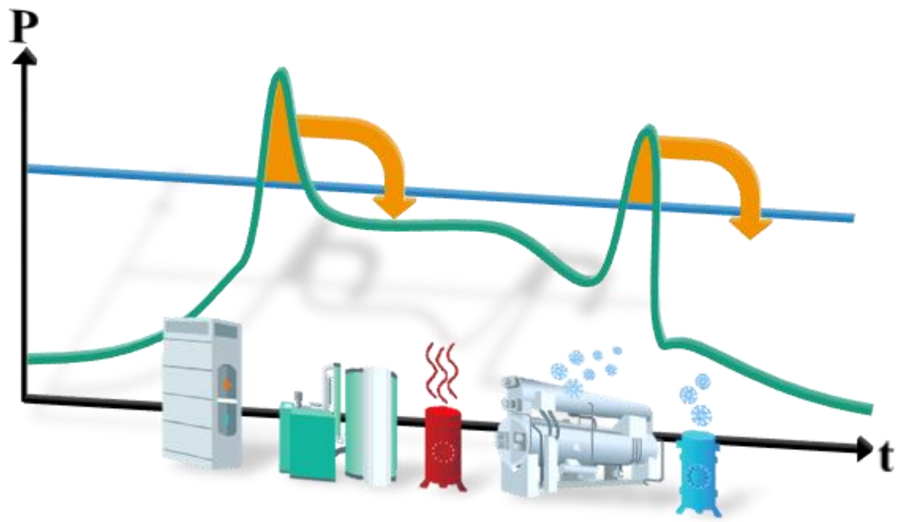
SUMMARY, PUBLICATIONS, CONTACT



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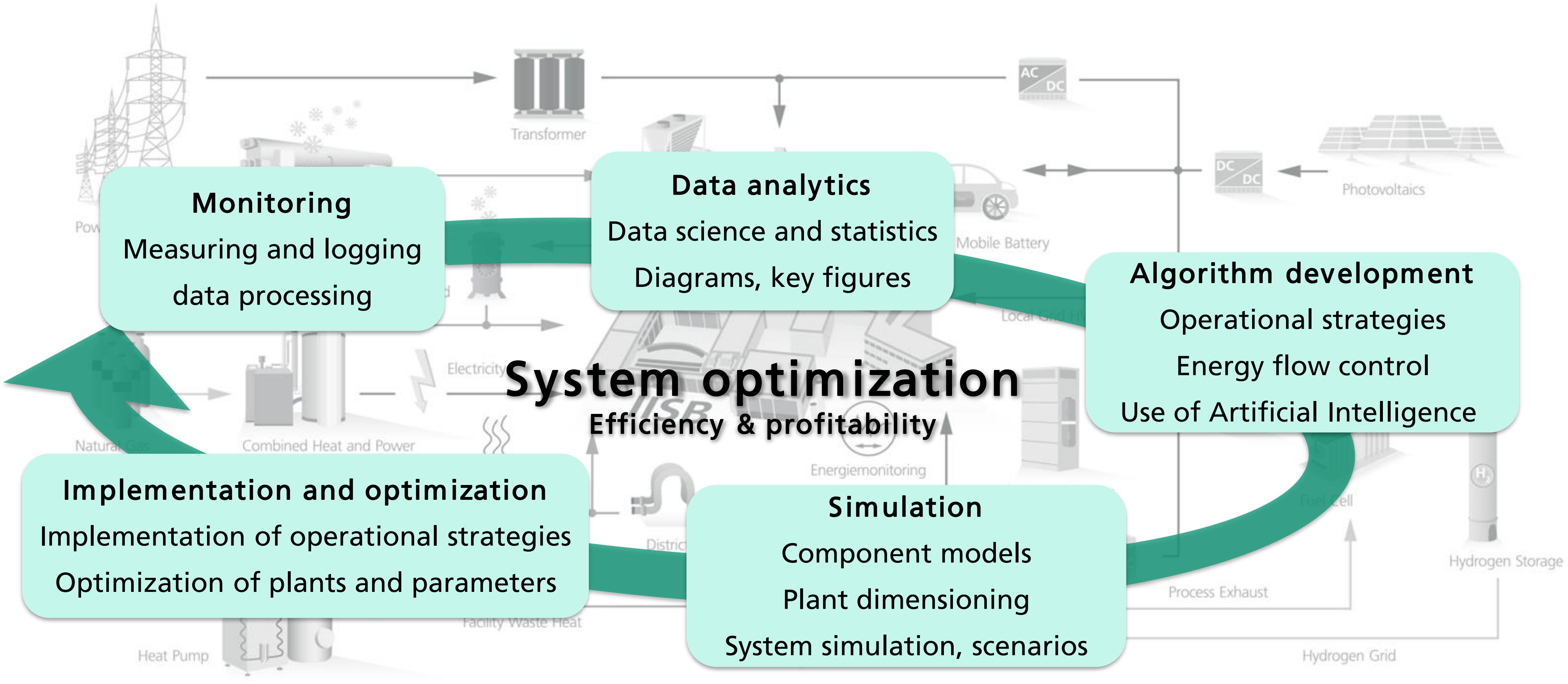
General approach and summary



Relevant publications (1)

- Scientific papers and books

[Gei21] J. Geiling, M. Steinberger, F. Ortner, R. Seyfried, A. Nuss, F. Uhrig, C. Lange, R. Öchsner, P. Wasserscheid, M. März, P. Preuster. „Combined dynamic operation of PEM fuel cell and continuous dehydrogenation of perhydro-dibenzyltoluene". *International Journal of Hydrogen Energy* 46.72 (2021), S. 35662 – 35677. ISSN: 0360-3199. DOI: 10.1016/j.ijhydene.2021.08.034

[Lan20] C. Lange, A. Rueß, A. Nuß, R. Öchsner, M. März. „Dimensioning battery energy storage systems for peak shaving based on a real-time control algorithm". *Applied Energy* 280 (2020), 115993. ISSN: 306-2619. DOI: 10.1016/j.apenergy.2020.115993.

[Och19] R. Öchsner, A. Nuß, C. Lange, A. Rueß. „Research Platform: Decentralized Energy System for Sector Coupling". *Chemical Engineering & Technology* 42.9 (2019), S. 1886–1894. DOI: 10.1002/ceat.201800714.

[Pul19a] P. Puls, C. Lange, R. Öchsner. „Hybrid Cooling Towers in a Free-Cooling Application: Modeling and Field Measurement Verification". *Chemical Engineering & Technology* 42.9 (2019), S. 1871 – 1878. DOI: 10.1002/ceat.201800712.

[Mar19] M. März, R. Öchsner (Hrsg.). „Innovative Technologien für intelligente dezentrale Energiesysteme. Stuttgart: Fraunhofer Verlag (2019). ISBN: 9783839614860.

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Relevant publications (2)

- PhD-Thesis

[Lan21a] C. Lange. „Energiesektoren-übergreifende Lastspitzenreduktion mit elektrischen und thermischen Energiespeichern“. PhD-Thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) (2021). URN: urn:nbn:de:bvb:29-opus4-169778.

[Pul19b] P. Puls. „Simulationsgestützte Effizienzoptimierung von industriellen Kaltwassersystemen mit thermischen Speichern“. PhD-Thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) (2019). URN: urn:nbn:de:bvb:29-opus4-108054.

[Ste18] M. Steinberger. „Verstromung von wasserstoffreichen Gasgemischen mit PEM-Brennstoffzellen am Beispiel einer Epitaxieanlage“. PhD-Thesis, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) (2018). ISBN: 978-3-8439-3887-7.

- Presentations

[Lan21b] C. Lange. „BHKW des Jahres 2020. BHKW mit Wärmespeicher und Batterie zur Strom-/Wärmeversorgung sowie Lastspitzenreduktion “. Presentation. *BHKW 2021 – Innovative Technologien und neue Rahmenbedingungen*, 09.11.2021 – 10.11.2021, Magdeburg (2021). DOI: 10.13140/RG.2.2.26423.80803.

[IISB19] IISB. "Energiesysteme neu denken“. Symposium. Presentations (2019). Available online: https://www.iisb.fraunhofer.de/en/press_media/events/eroeffnung_bau_b.html (access: 15.03.2021).

[Lan19] C. Lange, A. Nuß, A. Rueß, R. Öchsner. „Total System Control (ToSyCo) for Peak Shaving and Efficiency Enhancement“. Presentation. *International Renewable Energy Storage Conference (IRES)*, 12.03.2019 – 14.03.2019, Düsseldorf (2019). DOI: 10.13140/RG.2.2.13002.03520.

Contact

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Project website for ProEnergie

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