ETH zürich

# Energy hub modelling and optimisation

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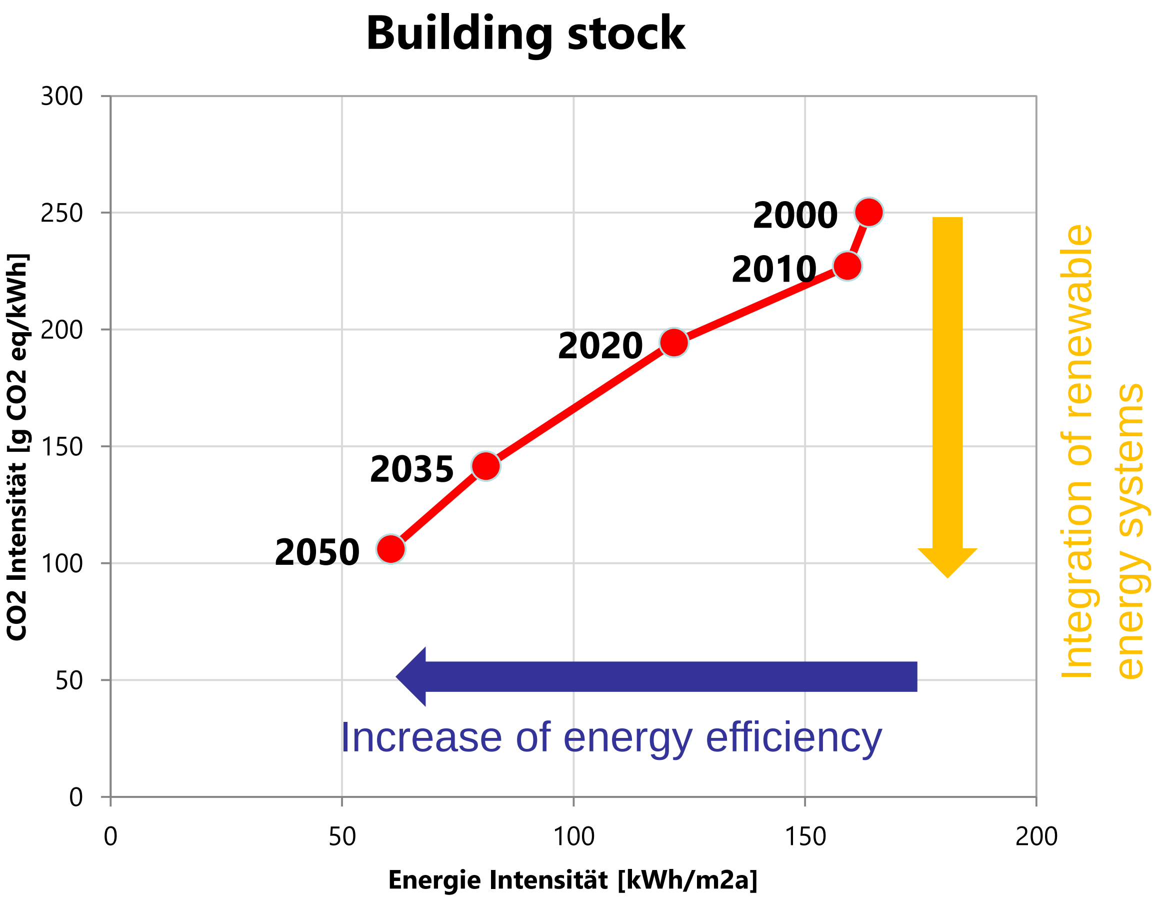
# Structure of the presentation

- Multi energy hubs
- Modelling of energy hubs
- Application example

# Goals of the energy strategy

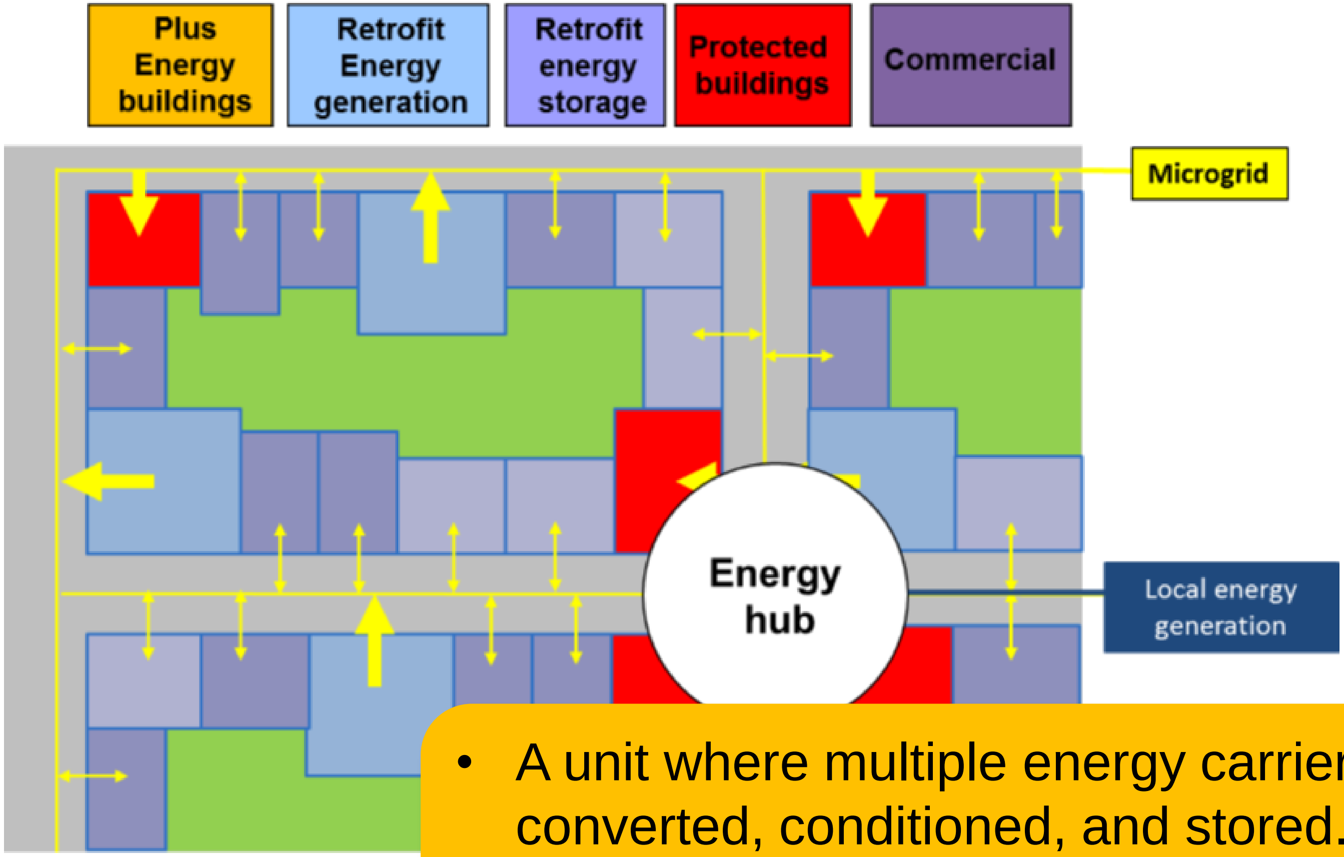



Future GHG emission goals requires **combination of measures**

**-> Methods** which allow for a **detailed energy performance analysis** and integration of renewables

# Multi-Energy hub systems

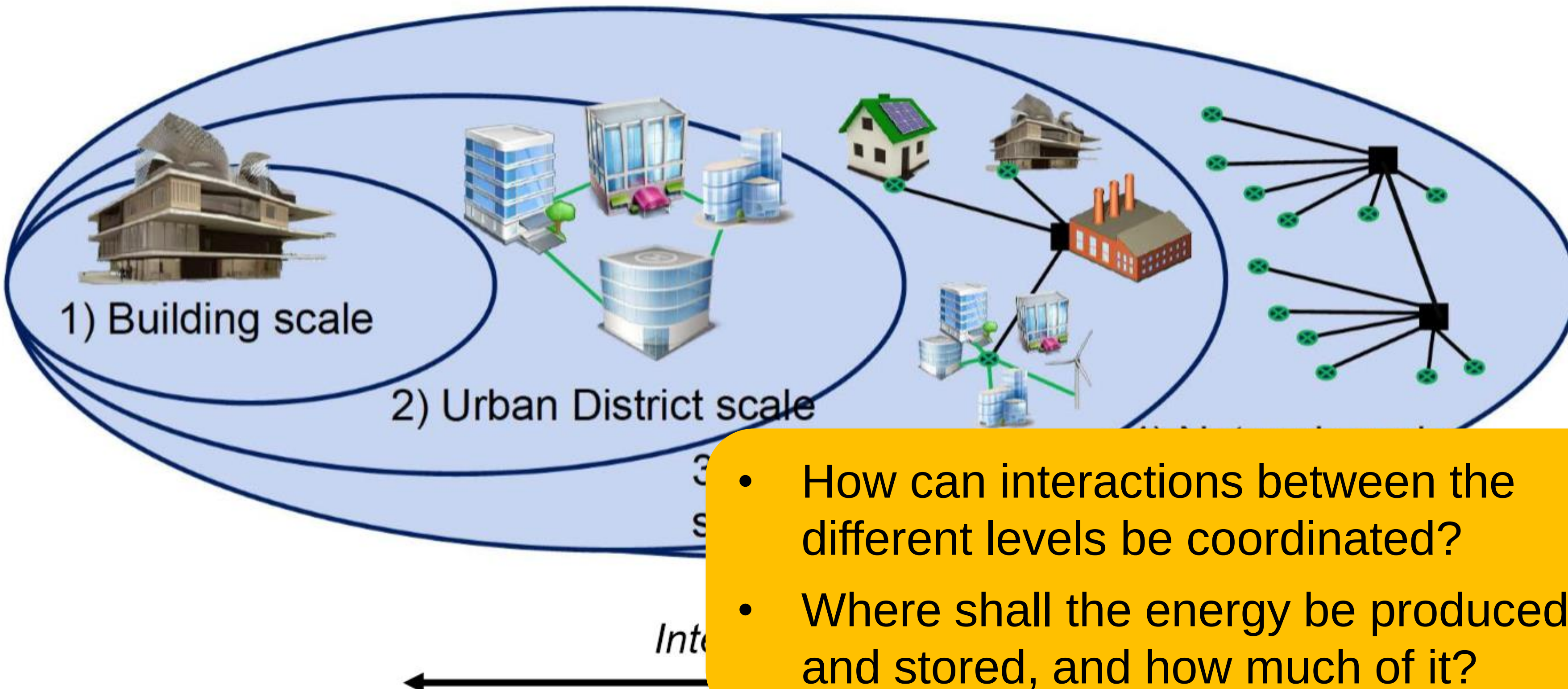
From buildings to neighborhoods …
How should a decentralized energy system be designed and operated?




- A unit where multiple energy carriers can be converted, conditioned, and stored.
- Interface between different energy infrastructures and/or loads.

# Multi-Energy hub systems … why optimisation

From buildings to neighborhoods …
How should a decentralized energy system be designed and operated?

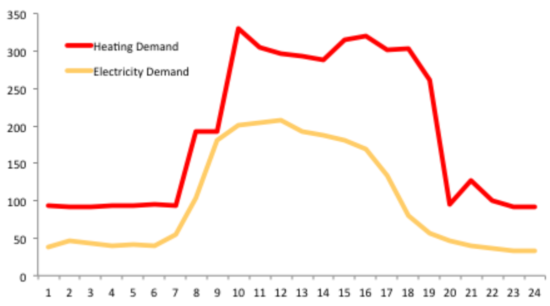


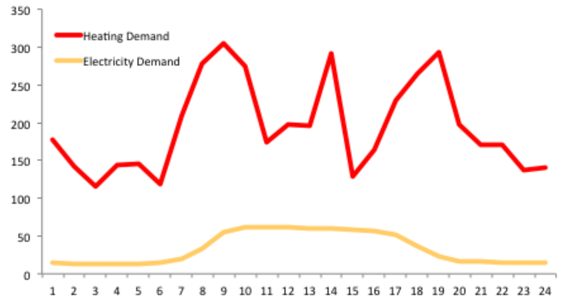

- How can interactions between the different levels be coordinated?
- Where shall the energy be produced and stored, and how much of it?

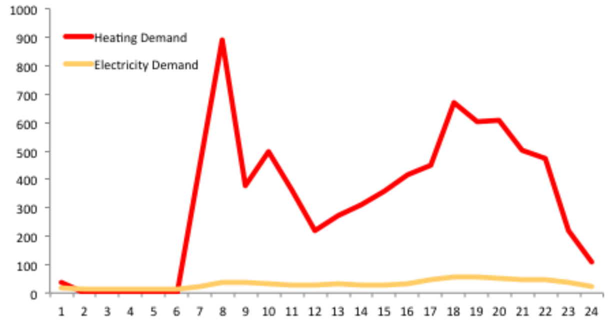
Minimize **costs** and/or **emissions**, maximize **autonomy**, etc…

# Complexity of integration

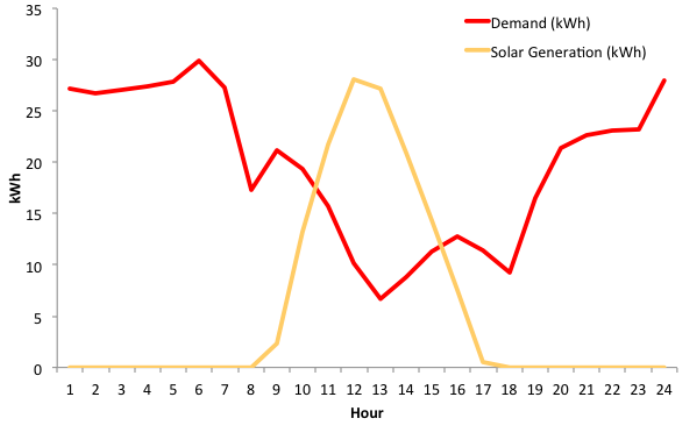
- Temporal and spatial variation in electricity, heating, and cooling demands



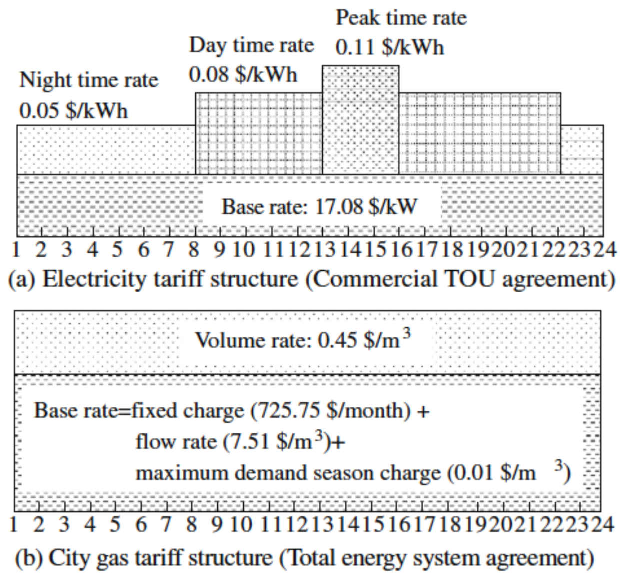




- Intermittency of certain types of renewable technologies (e.g. PV and wind turbines)



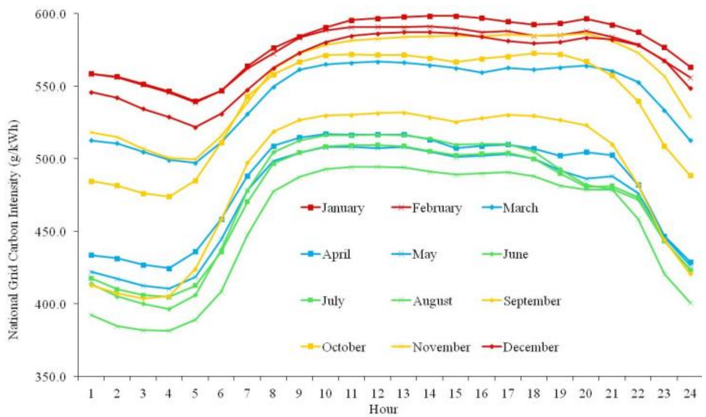
# Complexity of integration

- Variable fuel pricing




source: Ren and Gao, 2010

- Temporal variability in carbon intensity of the grid electricity



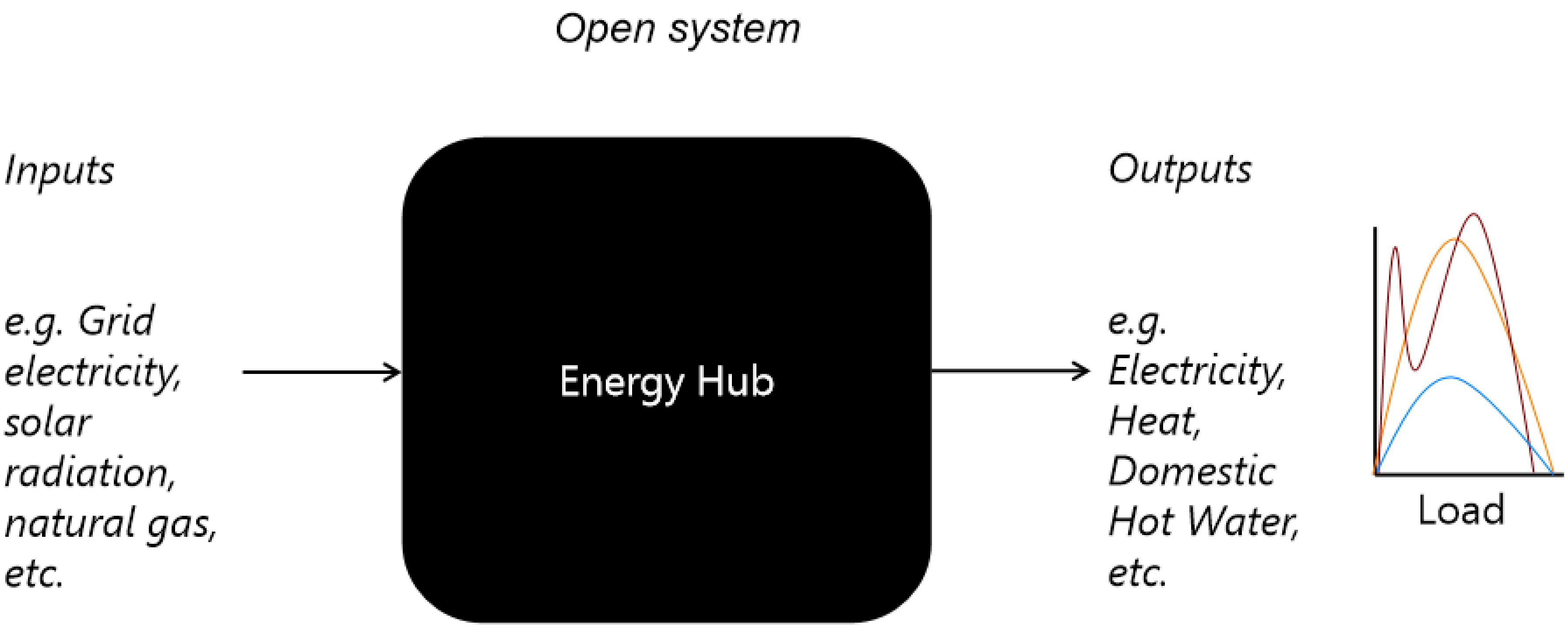

Different technologies with different fuels and different efficiencies operating at different times.

Carbon intensity of Swiss electricity grid?

- Summer vs. winter?
- Day vs. night?

# Modelling of Energy hubs

# Modelling of energy hubs

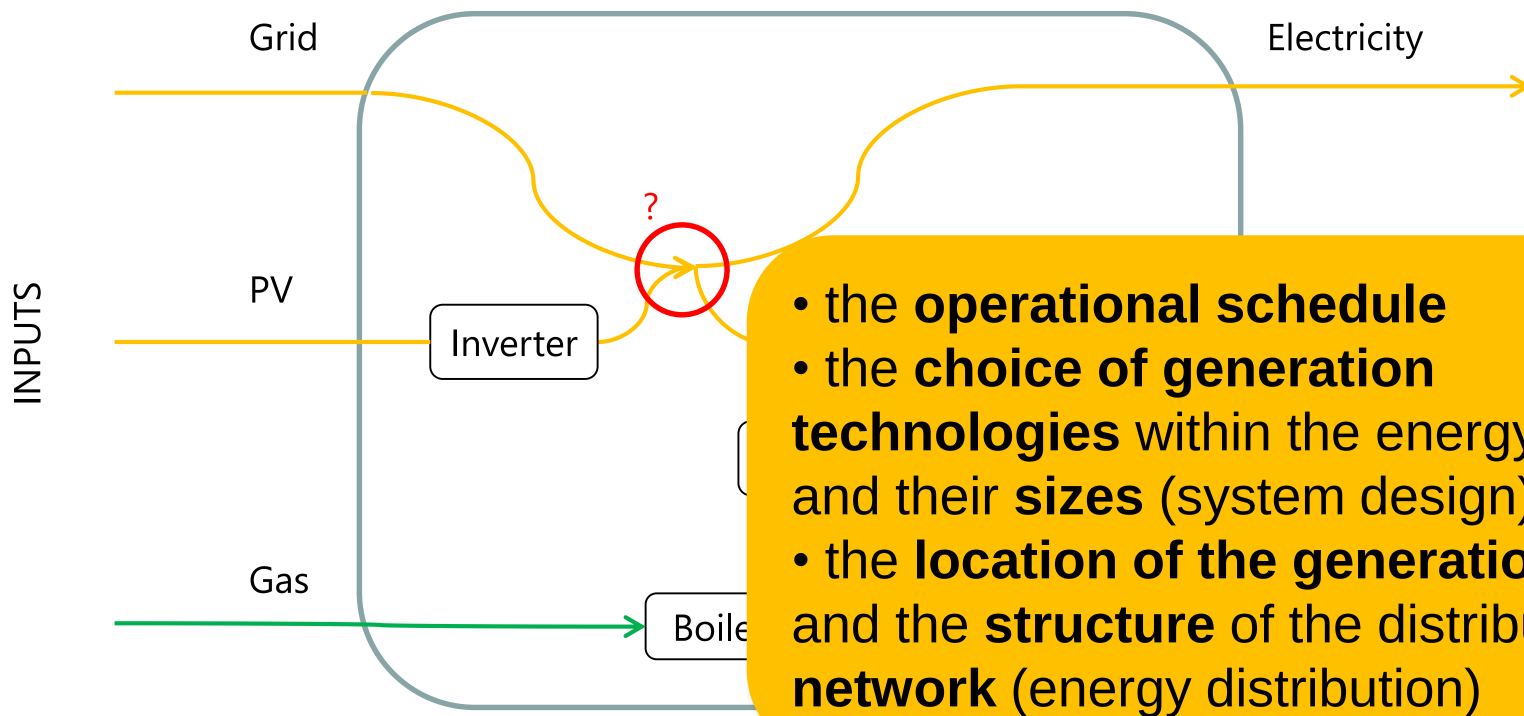



What happens in the black box?

# What is an energy hub?

A clearly delineated system to convert and store multiple energy streams

How many degrees of freedom are there in this system?



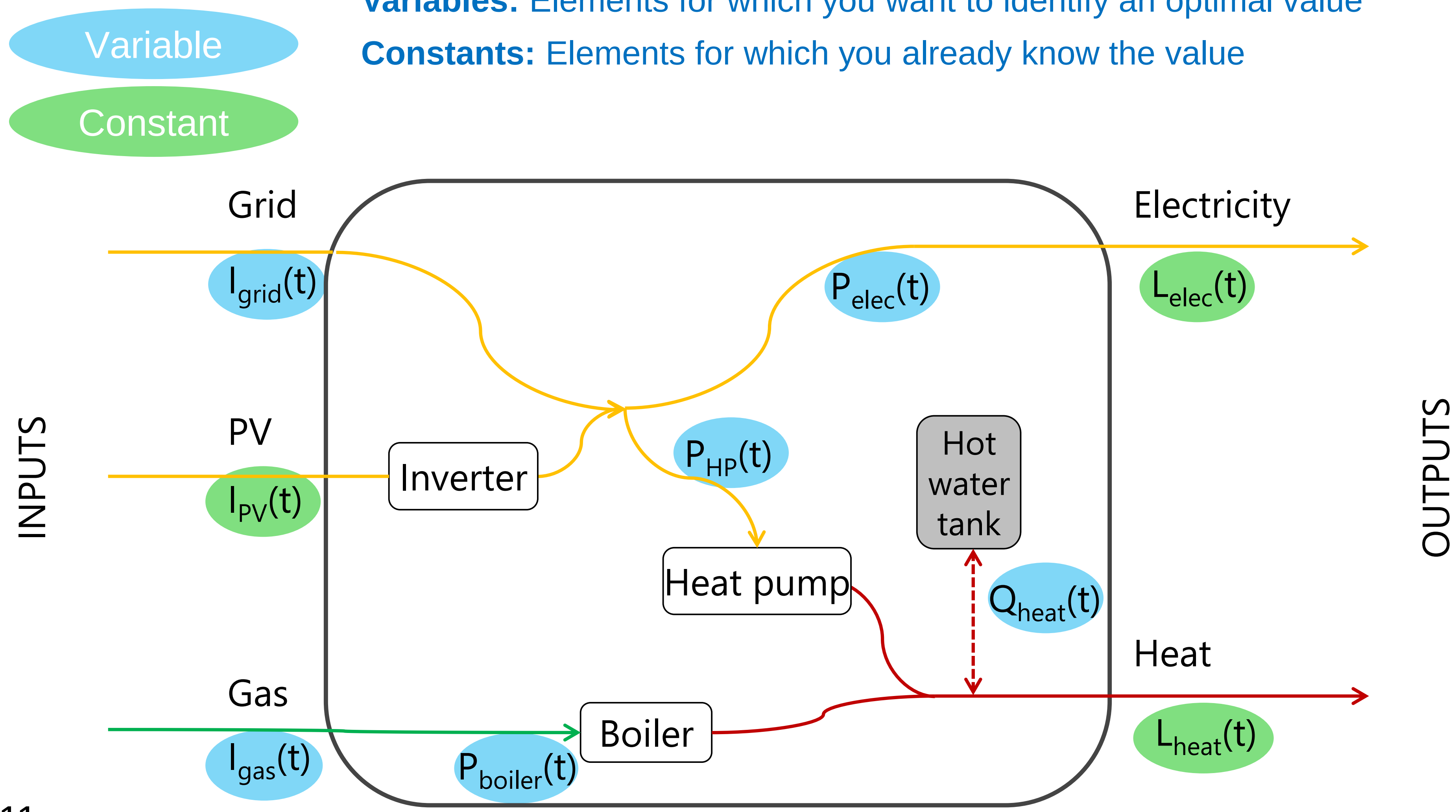

- the **operational schedule**
- the **choice of generation technologies** within the energy system and their **sizes** (system design)
- the **location of the generation units** and the **structure** of the distribution **network** (energy distribution)

# What is an energy hub model?

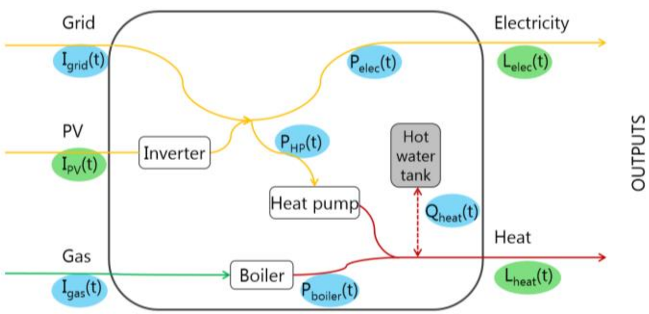
A mathematical representation of an energy hub that enables optimization

**Variables:** Elements for which you want to identify an optimal value

**Constants:** Elements for which you already know the value



# The equations




Conversion

Storage

Objective functions:
e.g. cost minimisation

$$min\ f = \sum G_j \times I_j(t)$$

$$L_k(t) = \Theta_{k,m} \times P_m(t) + A_n^{dis} Q_n^{dis}(t) - Q_n^{ch}(t)$$

Conversion

Charging/ discharging

$$E_n(t+1) = A_n^* E_n(t) + A_n^{ch} Q_n^{ch}(t) - Q_n^{dis}(t)$$

Continuity

$$I_j(t) \leq I_j^{max}(t),\ 0 \leq P_m(t) \leq P_m^{max},\ E_n(t) \leq E_n^{max}$$

Input capacity

Conversion capacity

Storage capacity



R. Evins, K. Orehounig, V. Dorer & J. Carmeliet, New formulations of the energy hub model to address operational constraints, Energy journal, vol. 73, pp. 387-398, August 2014.

# Energy Hub formulation – typical constraints

Objective function

$$min\ f = \sum G_j \times I_j(t)$$

Load balance constraint

$$L_k(t) = \Theta_{k,m} \times P_m(t) + A_n^{dis} Q_n^{dis}(t) - Q_n^{ch}(t)$$

→ Sum of energy outputs from technologies must be sufficient to provide for demand at the given timestep

Storage continuity constraint

$$E_n(t+1) = A_n^{*} E_n(t) + A_n^{ch} Q_n^{ch}(t) - Q_n^{dis}(t)$$

→ Storage inputs and outputs determine the state of charge at the next timestep.

Capacity constraints

$$I_j(t) \leq I_j^{max}(t),\ 0 \leq P_m(t) \leq P_m^{max},\ E_n(t) \leq E_n^{max}$$

→ Conversion technologies cannot produce more than their capacities. Storages must not be filled more than their capacities.

Storage charge/discharge constraints

$$Q_n^{ch}(t) \leq M d_n(t),\ Q_n^{dis}(t) \leq M\,(1 - d_n(t))$$

→ Storages can only be charged/discharged at a maximum rate.

Part-load constraints

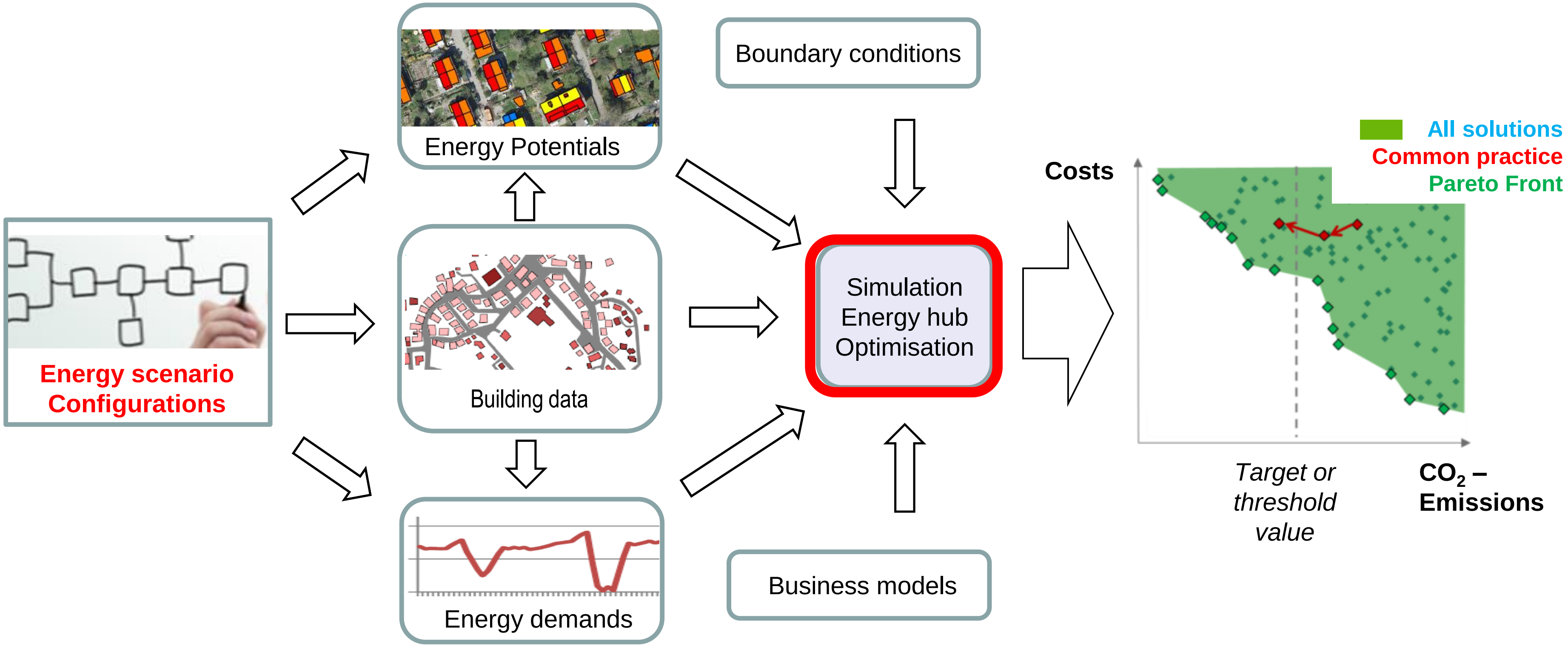
$$P_m^{min} b_m(t) \leq P_m(t),\ P_m(t) \leq M b_m(t)$$

→ Conversion technologies cannot produce below a given power level.

**...**

# Application

# Modelling of Energy Hubs



# Integration of Decentralized energy systems

The village of Zernez

- Energy sustainable community
- Remove building related $CO_2$ emissions

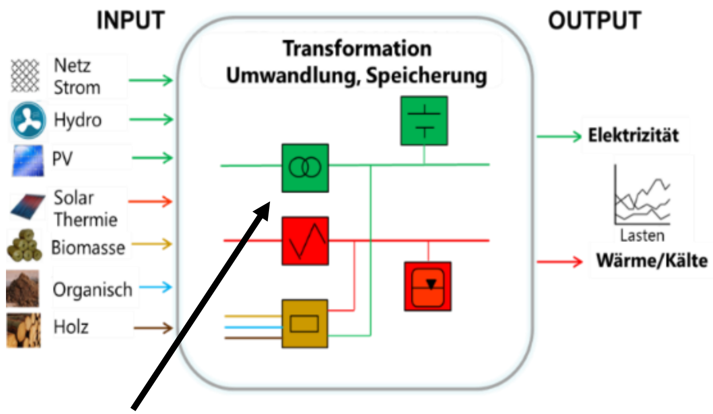


*Project partners:*

ETH zürich NSL Netzwerk Stadt und Landschaft Network City and Landscape A/S Architecture and Building Systems ESD ecological systems design Energy Science Center Zernez Das Tor zum Nationalpark. AMSTEIN + WALTHERT

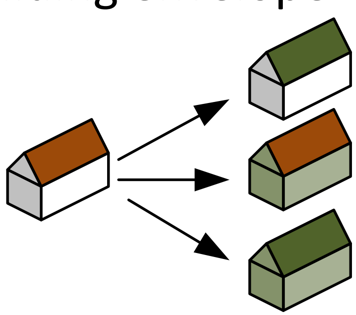
# Integration of Building systems

## 1. Building systems

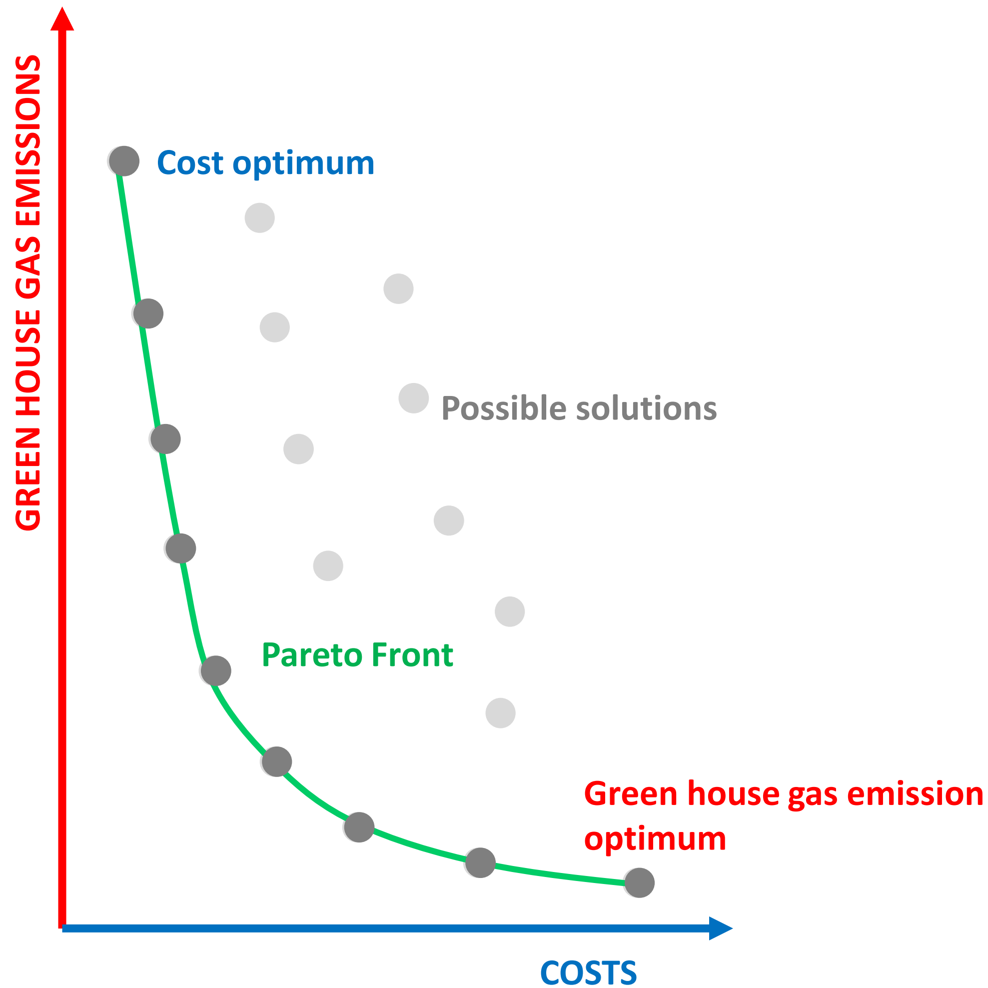



Heat pumps
Photovoltaic
Biomass boiler
Oil heating

## 2. Building envelope



## 3. Multi-criteria Analysis

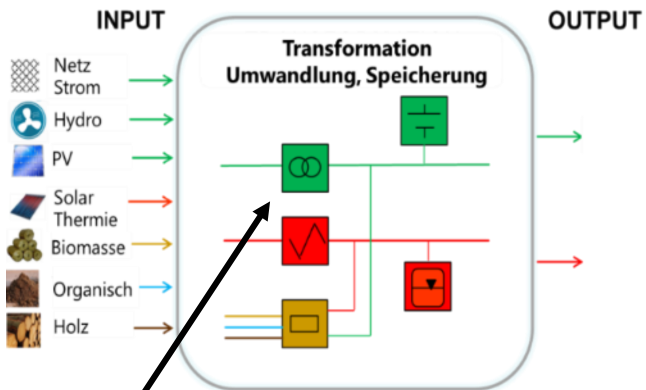





*R. Wu, G. Mavromatidis, K. Orehounig & J. Carmeliet, Multiobjective optimisation of energy systems and building envelope retrofit in a residential community. Applied Energy 190 (2017) 634–649*

# Integration of Building systems

## 1. Building systems

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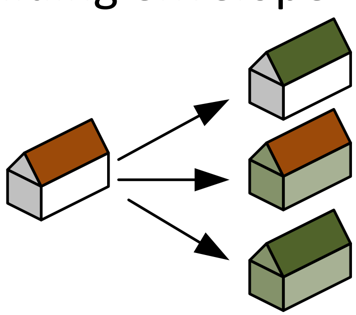

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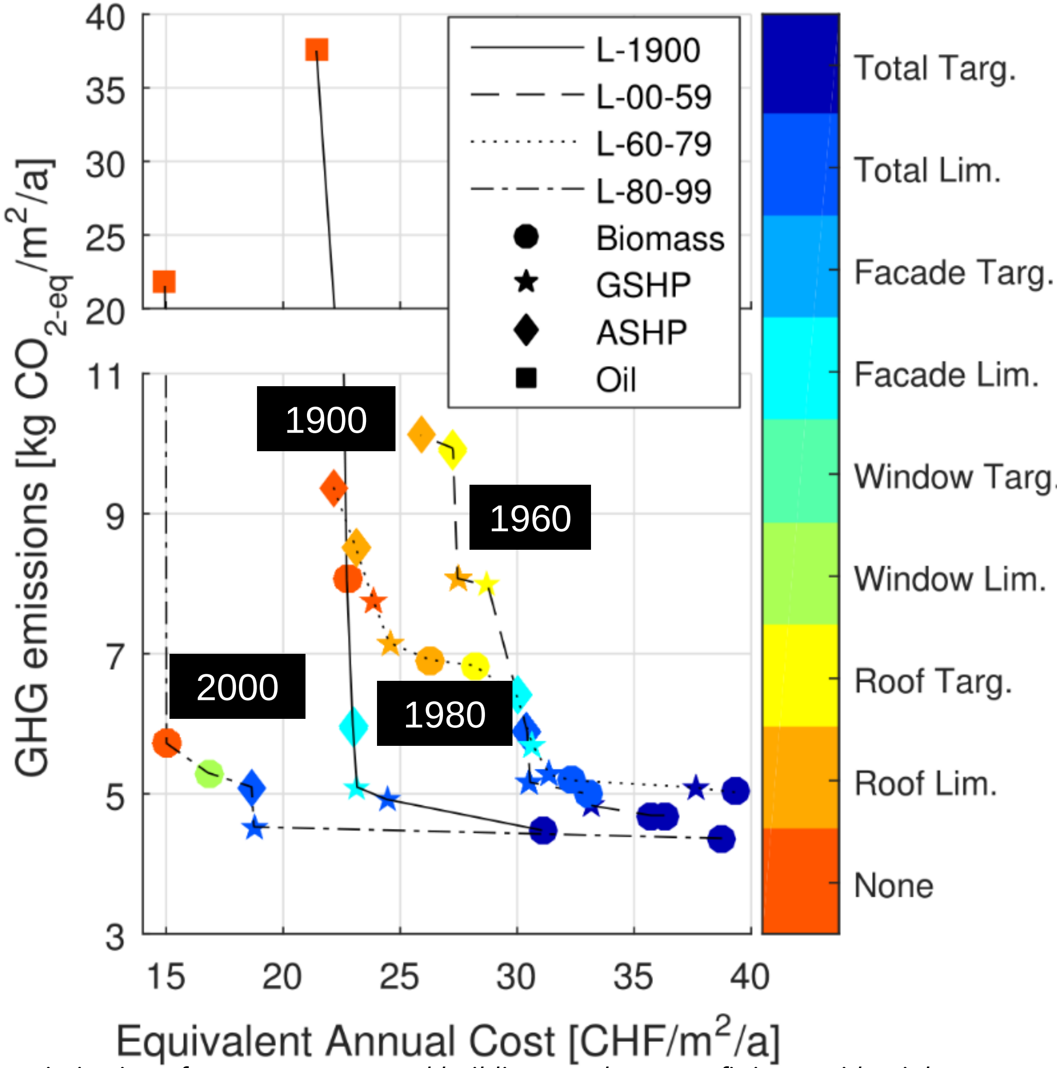


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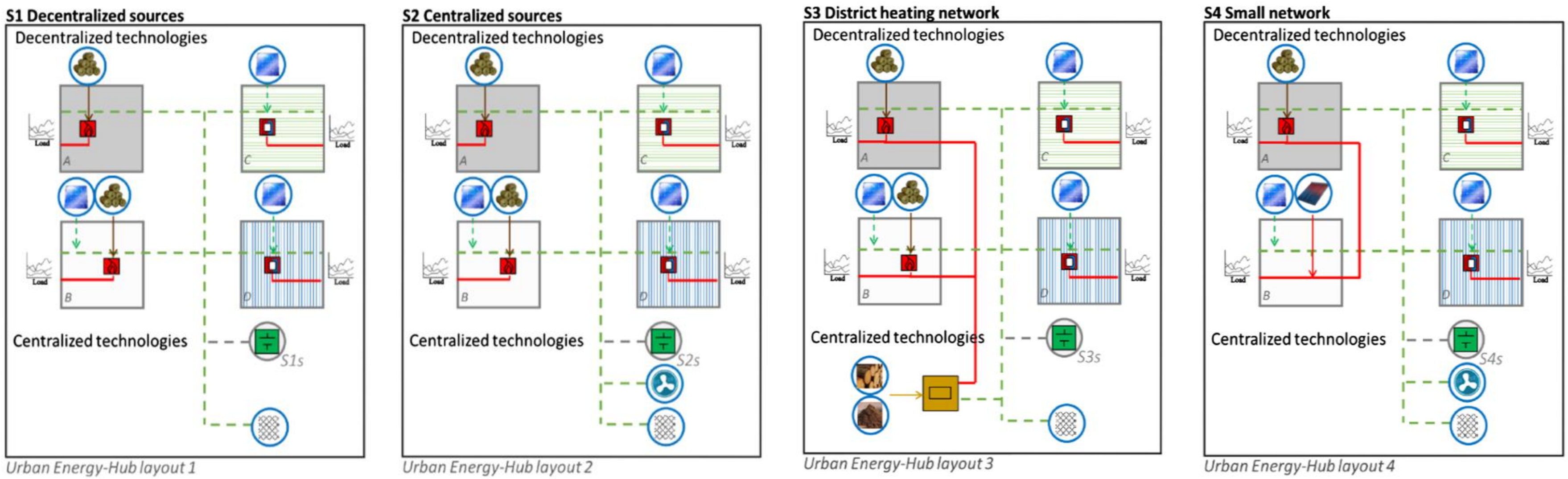
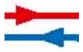
# Design of the energy system



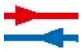

*Decentralized*

*Decentralized +*
*small hydro power*

*Decentralized*
*+*
*CHP*



*Decentralized +*
*small hydro power +*
*local networks*



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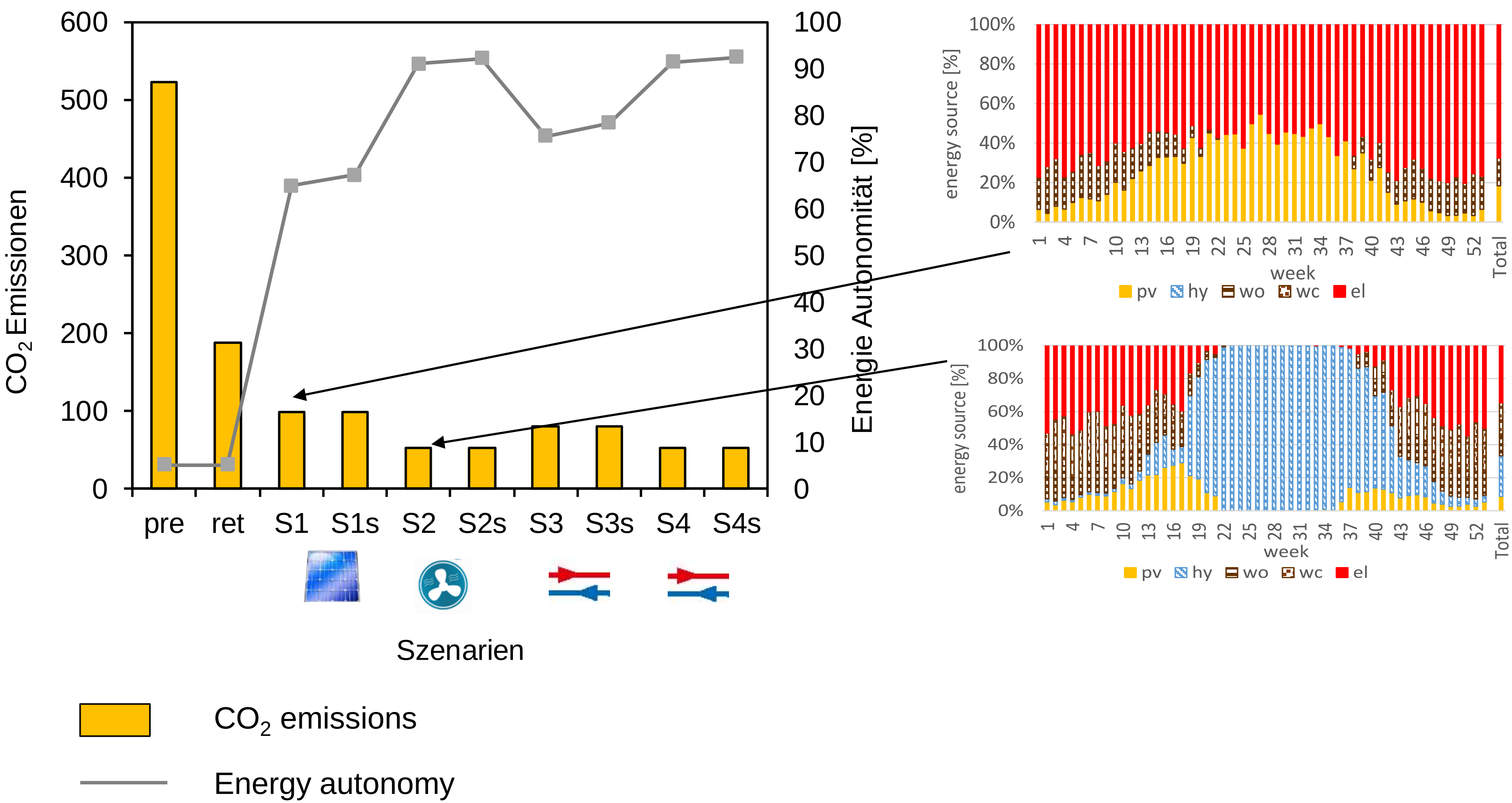





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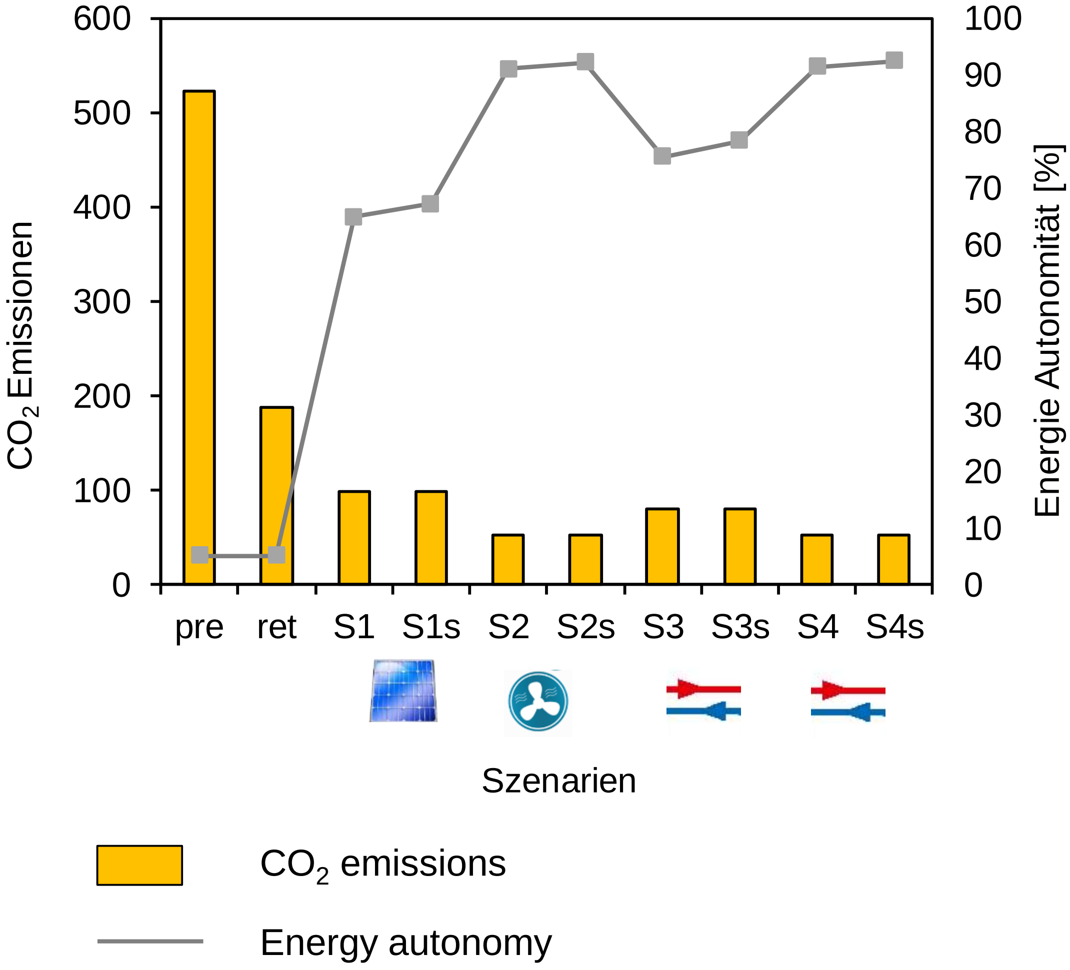


| | Neighbor-hood | village |
|---|---|---|
| Energy autonomy | **92%** | **83%** |
| Energy efficiency | **-55%** | **-62%** |
| $CO_2$ emissions | **-90%** | **-86%** |



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# Summary and Outlook

- Quick introduction into energy hub modelling
- Application examples at building and neighborhood scale

- Design your own energy hub

# Exercise (1)

Each person has a card representing a type of entity in a district energy system.

4 types of cards:

1. **Energy inputs:** You represent an external energy input to a district energy system
2. **Energy demands:** You represent an energy demand internal to a district energy system
3. **Energy conversion technologies:** You are a distributed energy conversion technology. You convert one form of energy into another.
4. **Energy storage technologies:** You are an energy storage technology. You store a specific type of energy.

Look at your card. What type of card do you have? What are your inputs and outputs?

# Exercise (2)

sccer | future energy efficient buildings & districts

Empa Materials Science and Technology

**Instructions:**

5 minutes: Look for partners who can supply your inputs and use your outputs. Try to make a complete chain (district energy system) from inputs to demands.

**Rules:**

1. Each chain must begin with inputs and end with demands.
2. Each chain must provide for (at least) the following demands:
    - electricity
    - space heating
    - domestic hot water
3. Each chain must include 3 or more conversion/storage technologies.
4. If you use an intermittent renewable conversion technology, you must have a corresponding storage or external energy input.

# Exercise (3)

**Questions:**

1. How many technologies are in your system?
2. How sustainable (carbon intensive) is your system?
3. How energy autonomous is your system?

**INPUTS**

Grid connection
Output: Electricity

District heating connection
Output: Heat

Gas network connection
Output: Natural gas

Oil delivery:
Output: Oil

Sun
Output: Solar radiation

Wind
Output: Wind

River water
Output: Moving water

Biomass
Output: Biomass

**DEMANDS**

Electricity demand
Required input: Electricity

Space heating demand
Required input: Heat

Hot water demand
Required input: Heat

Cooling demand
Required input: Chilled water

**CONVERSION TECHNOLOGIES**

Wind turbine:
Input: Wind
Output: Electricity

Small hydro plant
Input: Moving water
Output: Electricity

Solar photovoltaic system
Input: Solar radiation
Output: Electricity

Solar thermal system
Input: Solar radiation
Output: Heat

Gas boiler
Input: Gas
Output: Heat

Heat pump
Input: Electricity
Output: Heat

Electric boiler
Input: Electricity
Output: Heat

Biomass boiler
Input: Biomass
Output: Heat

Chiller
Input: Electricity
Output: Chilled water

**CONVERSION TECHNOLOGIES**

Absorption chiller
Input: Heat
Output: Chilled water

Combined heat-and-power (CHP) unit
Input: Gas
Output: Electricity, Heat

Fuel cell
Input: Hydrogen
Output: Electricity

Electrolyzer
Input: Electricity
Output: Hydrogen

STORAGE TECHNOLOGIES

Borehole heat storage
Stored energy: Heat

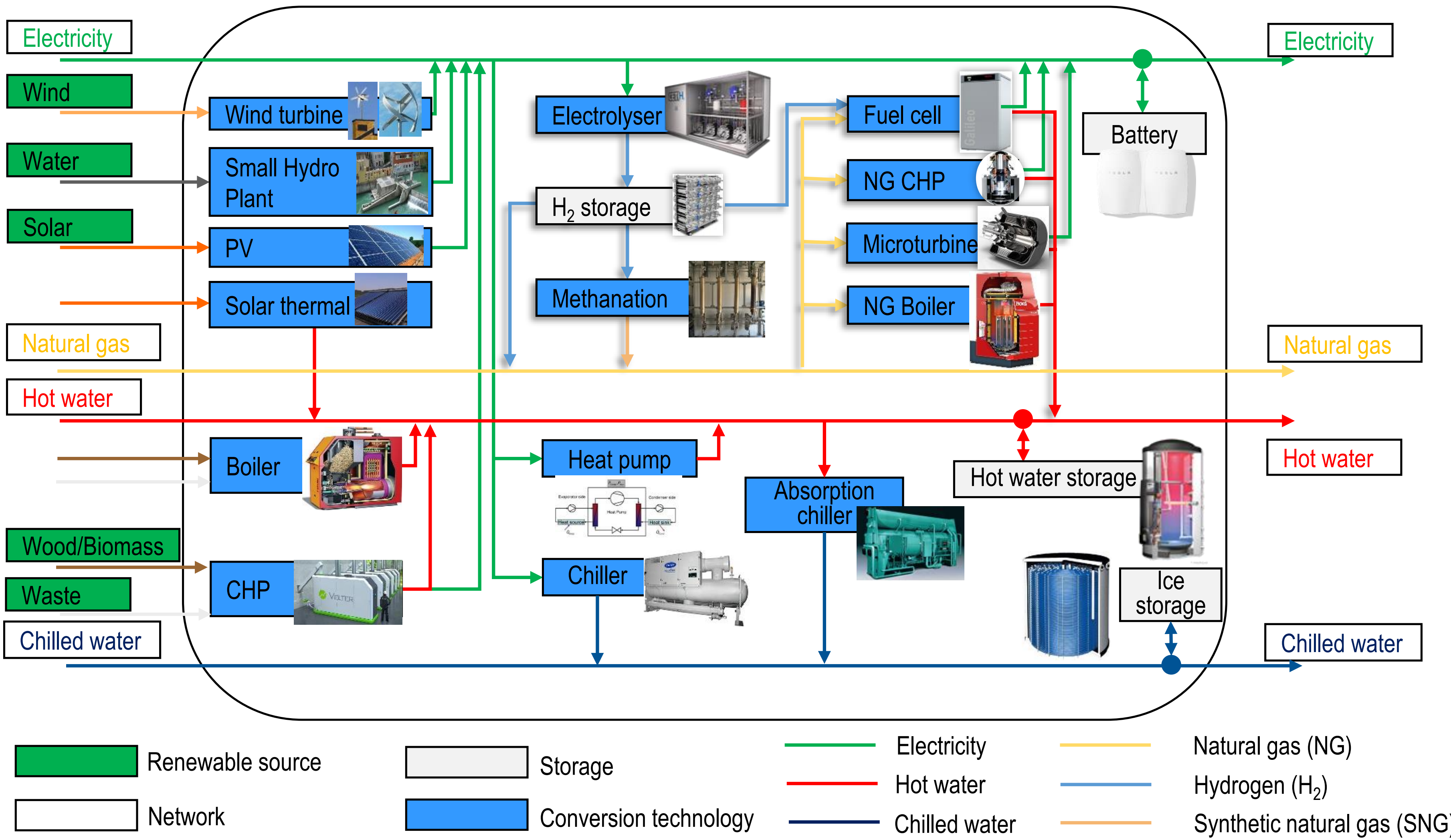
Hot water tank
Stored energy: Heat

Hydrogen tank
Stored energy: Hydrogen

Ice storage
Stored energy: Chilled water

Battery
Stored energy: Electricity

# Multi-Energy Hubs



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