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Comparison of CO_2 optimised energy systems for a residential building in Germany

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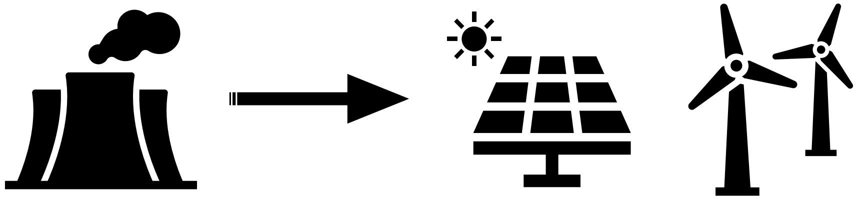
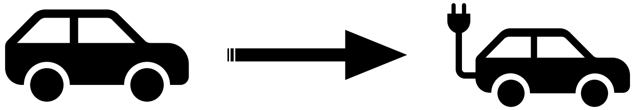
The challenge

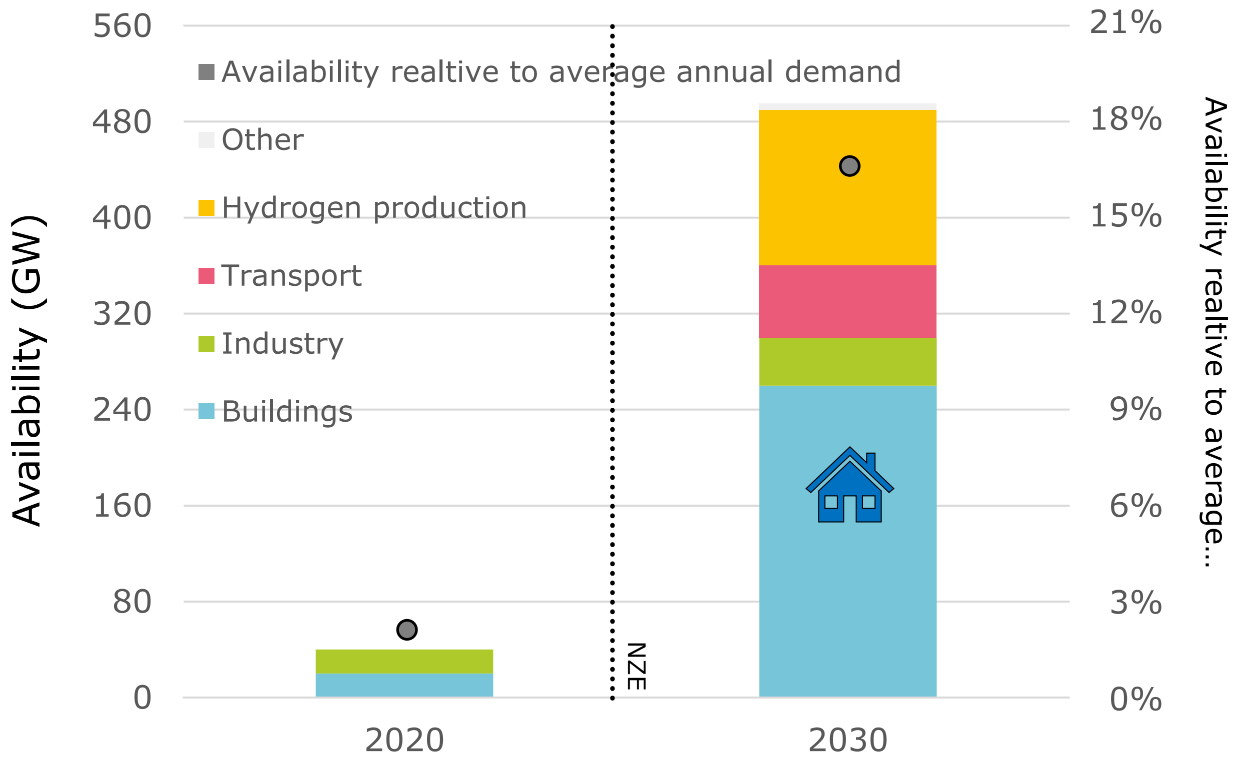
Replacing coal, gas and nuclear by new renewables



.. while at the same time the electricity demand rises due to electrification



Be flexible and consume energy when abundant



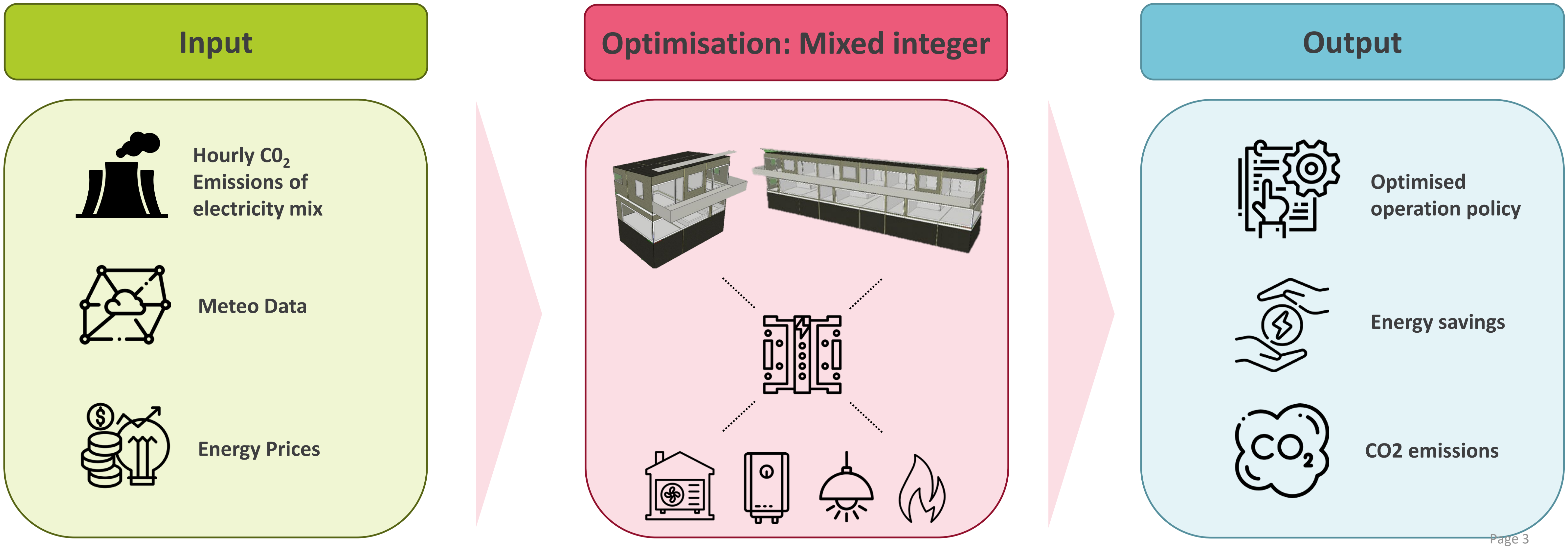
IEA, Demand response availability at times of highest flexibility needs and share in total flexibility provision in the Net Zero Scenario, 2020 and 2030

Source: https://www.iea.org/data-and-statistics/charts/demand-response-availability-at-times-of-highest-flexibility-needs-and-share-in-total-flexibility-provision-in-the-net-zero-scenario-2020-and-2030, IEA.

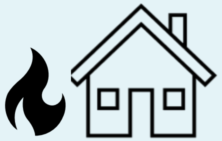
Objectives

1. Model the energy consumption of a house in Berlin
2. Compare different heating systems in terms of CO2 emissions

Simulation Toolbox HSLU Distributed Energy Management Suite - DISsuite™



Heating systems options and modelling assumptions



Sc.1: Gas boiler

Sc.2: Heat pump

Sc.4: HP + SOFC

Sc.6: Gas boiler + SOFC

Model house

- 140 m^2 Living area
- 5 Inhabitants
- Radiator heating with variable flow temperature
- 4 MWh_{el}/a Electrical demand
- 9.5 MWh_{th}/a Space heating
- 3.5 MWh_{th}/a Hot water

Heat pump assumptions

- Air source heat pump with R290 (propane) refrigerant
- 6 kW_{th} HP + 8 kW resistor
- Hourly COP and capacity constrains depending on outside temperature

Fuel cell assumptions

- Solid oxide fuel cell SOFC
- 1.5 kW_{el} (η_{el} = 60%)
- 0.75 kW_{th} (η_{th} = 30%)
- Operated on natural gas

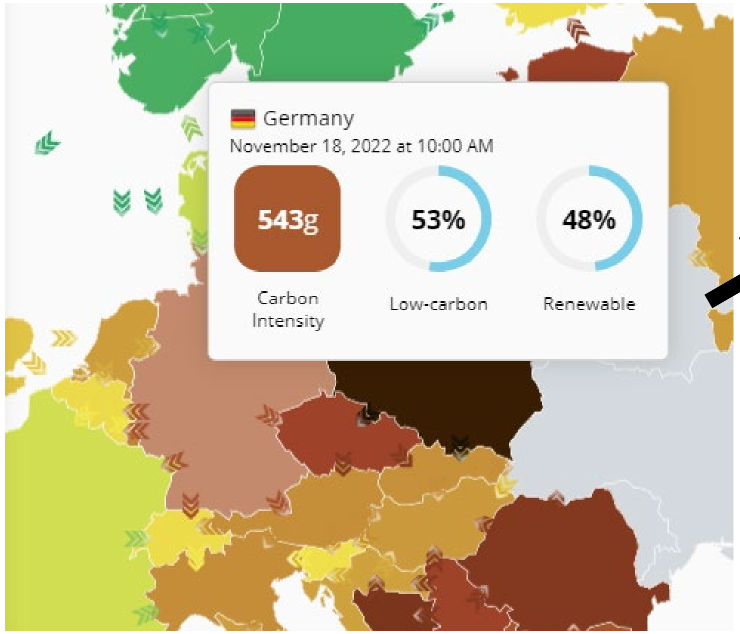
Thermal inertia for operational CO_2 optimisation

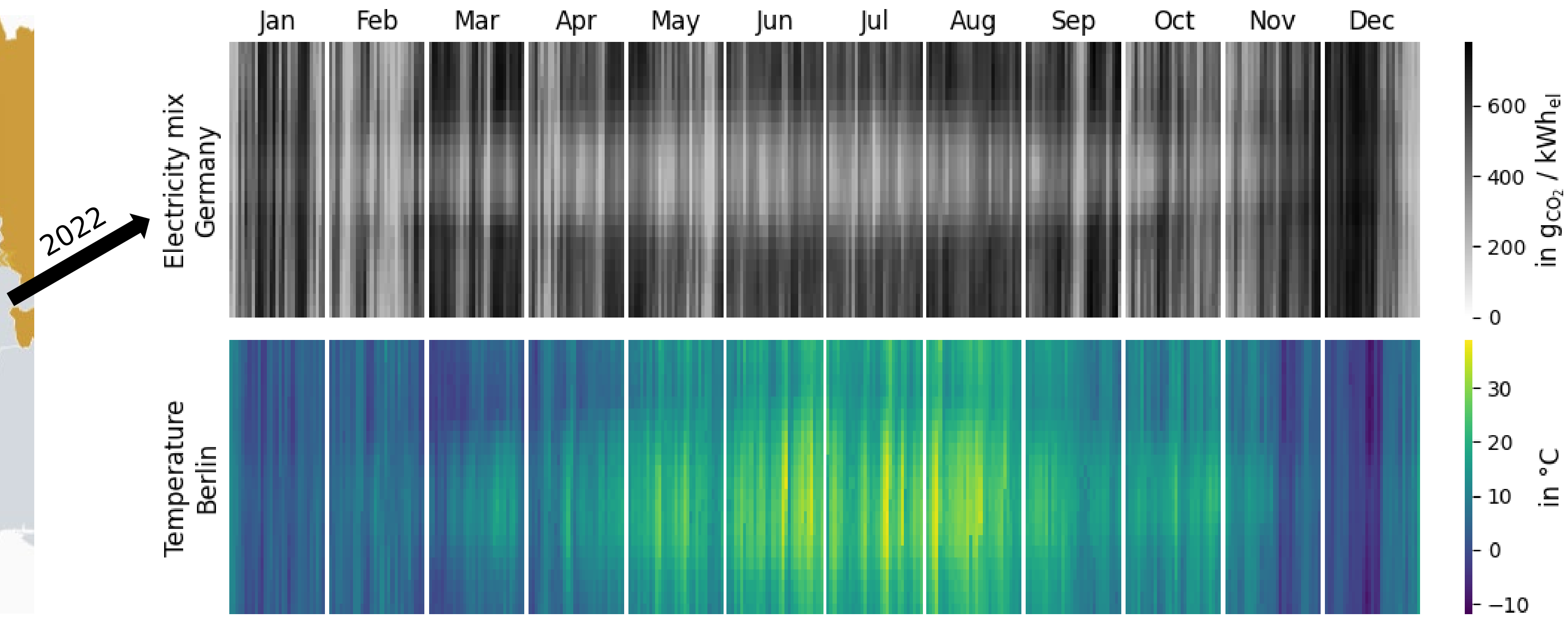
- Building mass + 220l hot water tank

Input data: Hourly electricity grid emissions from www.electricityMaps.com/

electricityMaps evaluates the hourly carbon footprint of the grid electricity. It considers:

- Cross border flows
- Hourly production and consumption for each country/bidding zone





Temperature from Deutscher Wetterdienst https://opendata.dwd.de/

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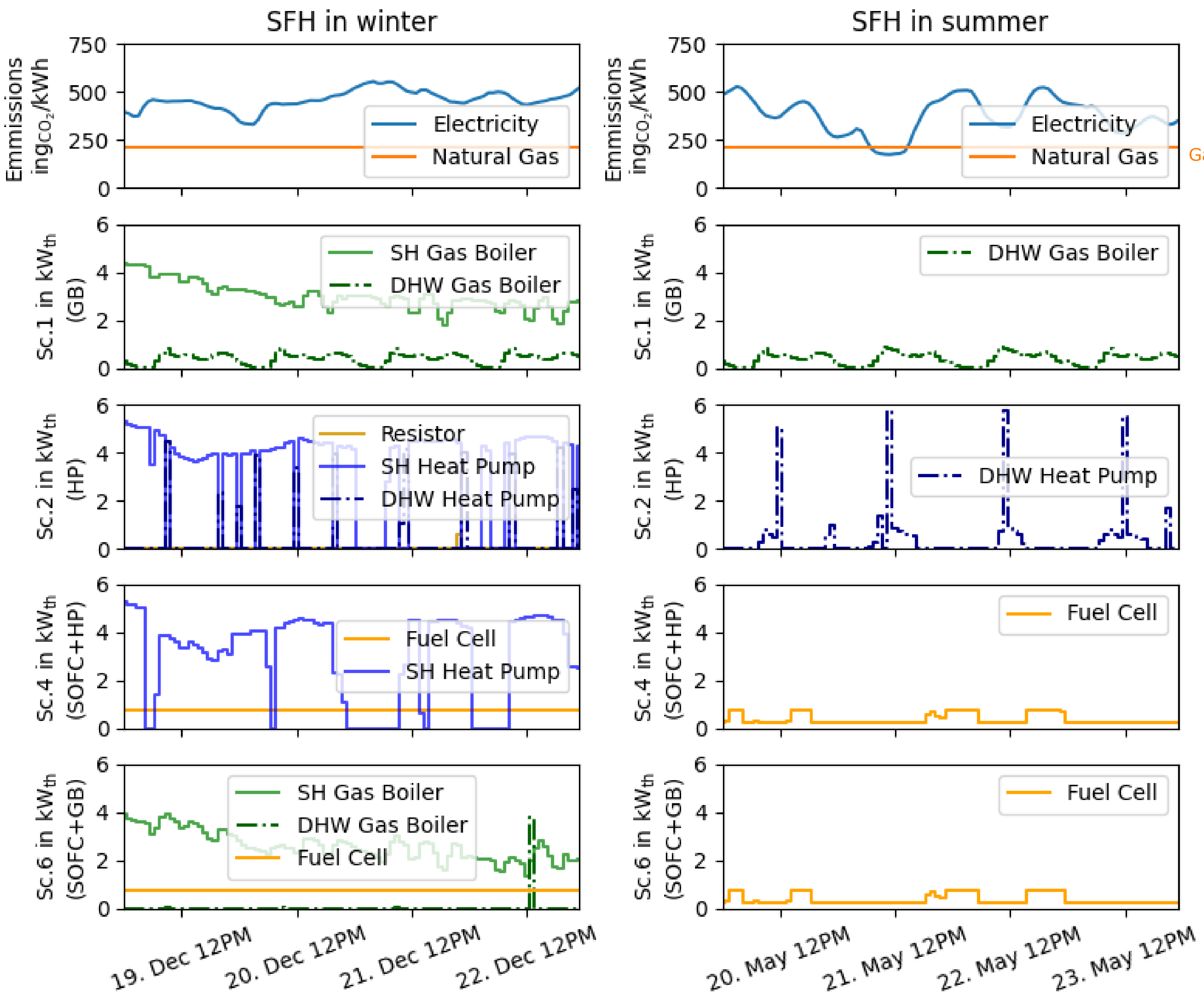
Results

Operational behaviour of different heating systems



Gas: Before conversion to electricity

Standalone gas boiler

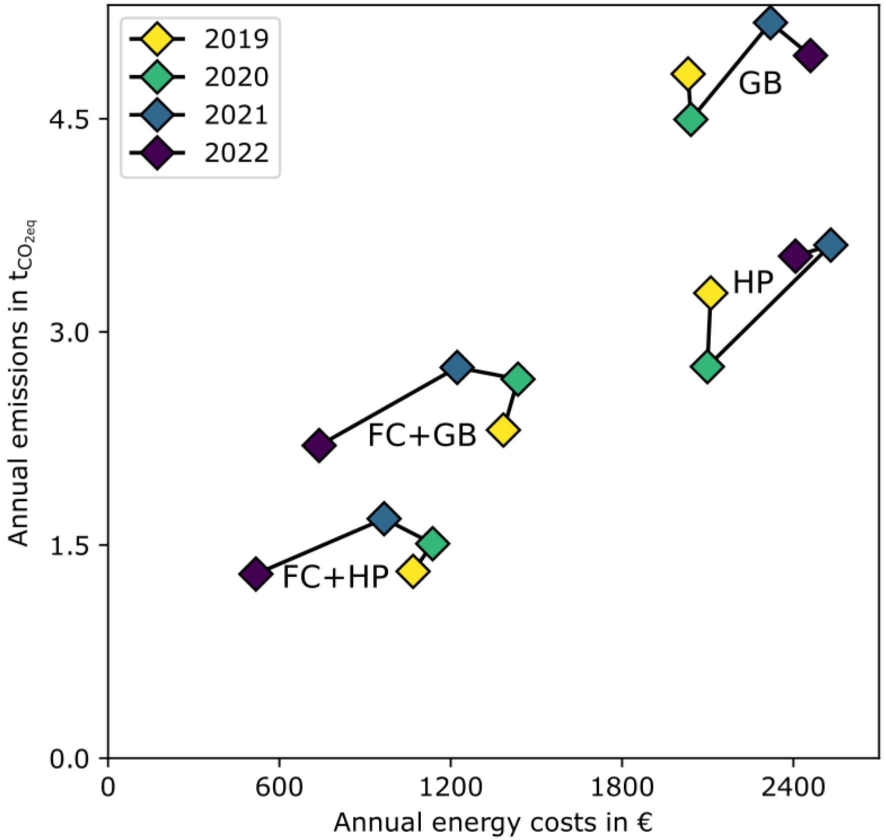
Standalone heat pump

Combination fuel cell + heat pump

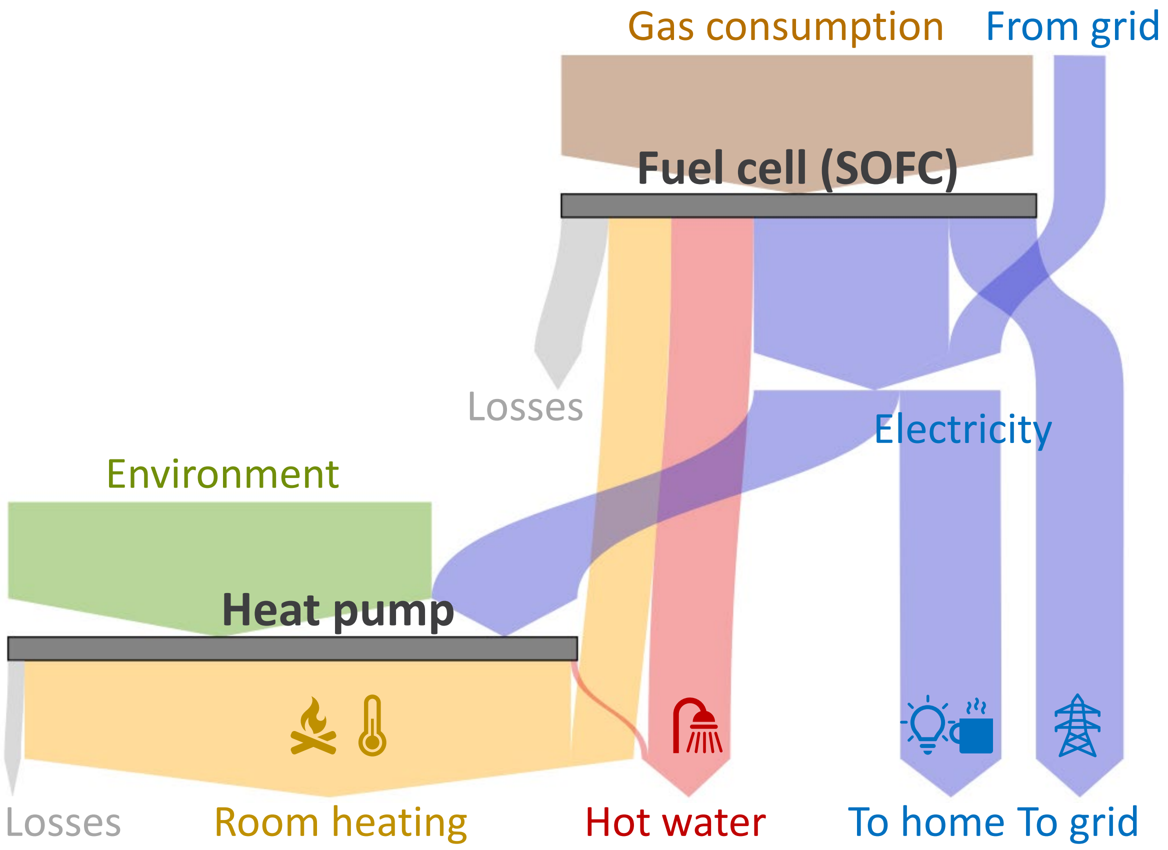
Combination fuel cell + gas boiler

Cost vs. Emissions

Comparison of annual figures



Example scenario: SOFC+HP in winter 2022



Summary and Outlook

Main findings

1. The combination of fuel cells and heat pumps is best in terms of emissions and energy costs
2. Standalone gas boiler is the worst scenario for each year
3. Biggest challenge for heat pumps in past years: Cold winter days with high shares of coal in the German electricity mix

Limitations (non-exhaustive)

- Future development of emission intensity
- CO2 optimised operation by HEMS requires forecasts of energy demand and emission intensity

Outlook

a. Cost-optimised vs. CO_2-optimised
b. LCA perspective on emissions and costs – go beyond the operational phase
c. Comparison to PV panels
d. Impact of increased thermal storage
e. Repeat for additional countries

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Questions?

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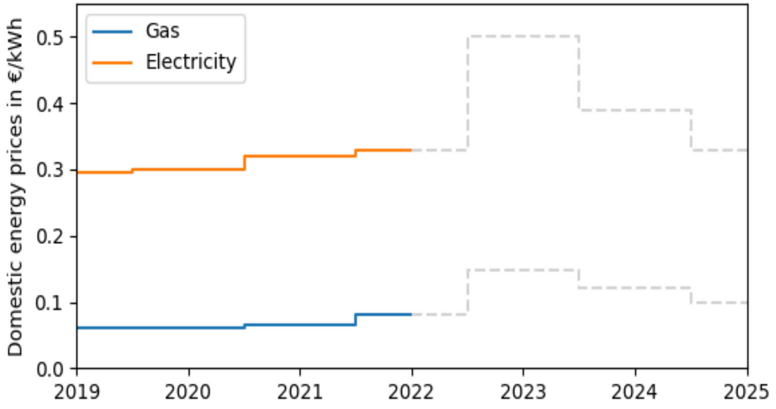
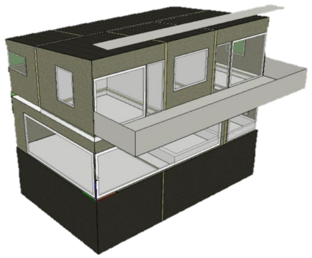
Input data

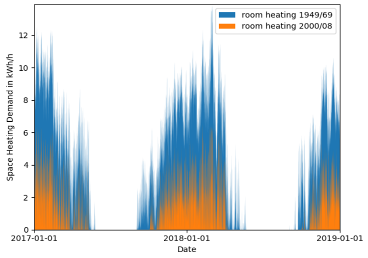
Energy price projections for domestic gas and electricity prices in Germany. The analysis considers price projections not more than three years into the future.



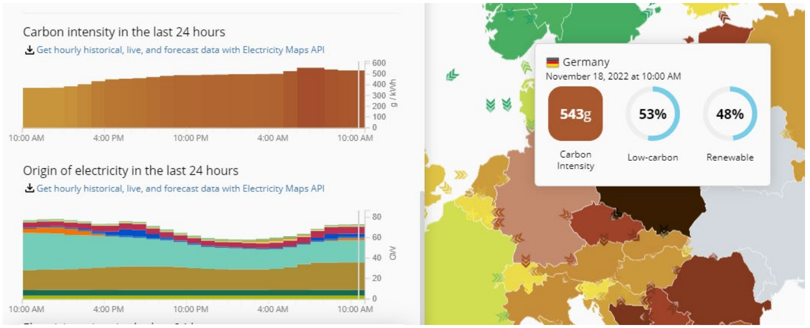
Hourly heat and electricity consumption profiles for a single- and multi-family house based on climate conditions as in Berlin abd building simulations by IGE.

The single-family house exhibits an electricity consumption of 4 MWh_{el}/y, while heat demand resembles a 140m² living area and.

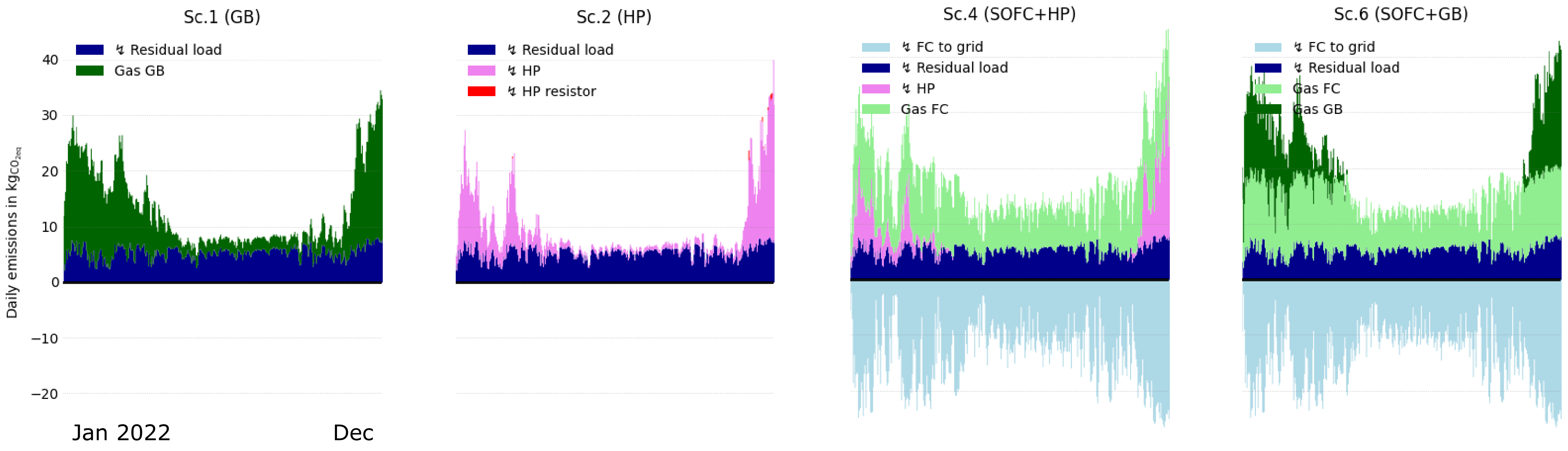




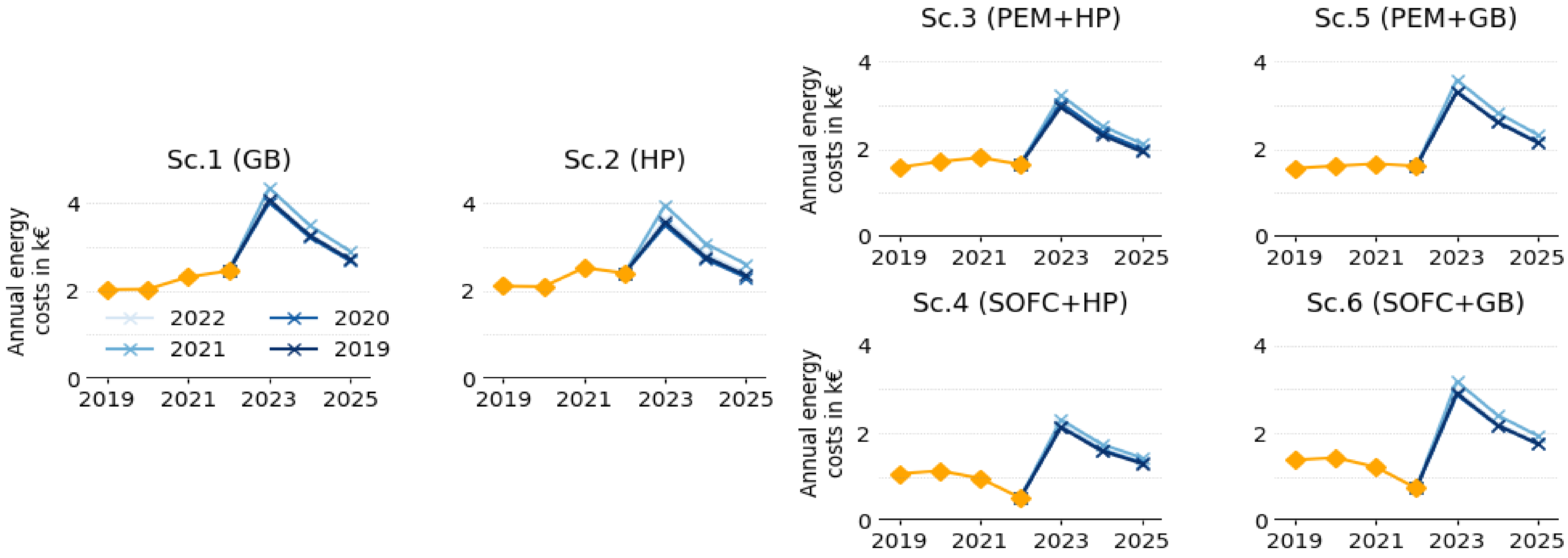
Hourly data for the electricity emissions in Germany for the year 2022 are purchased from https://electricitymap.org.



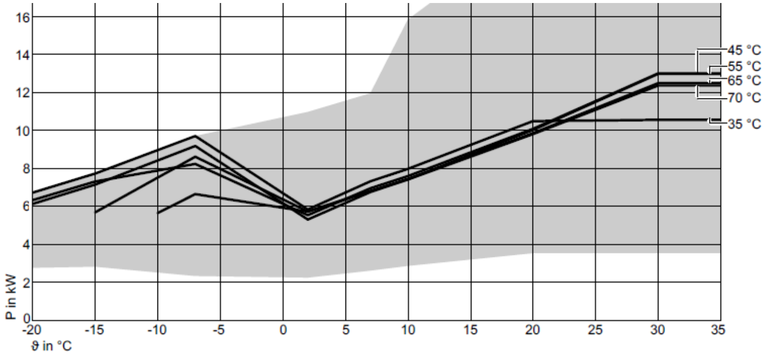
Daily CO2 emissions after optimisation for a few selected scenarios



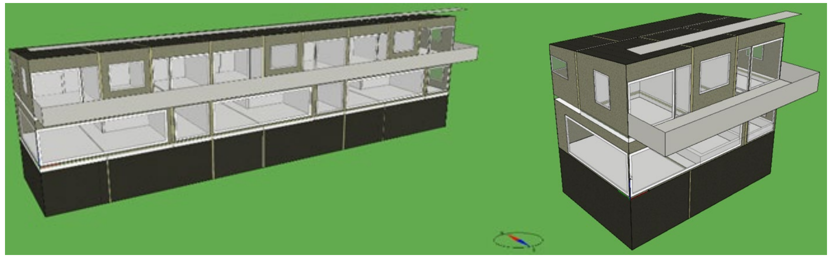
Energy costs when CO2 optimise



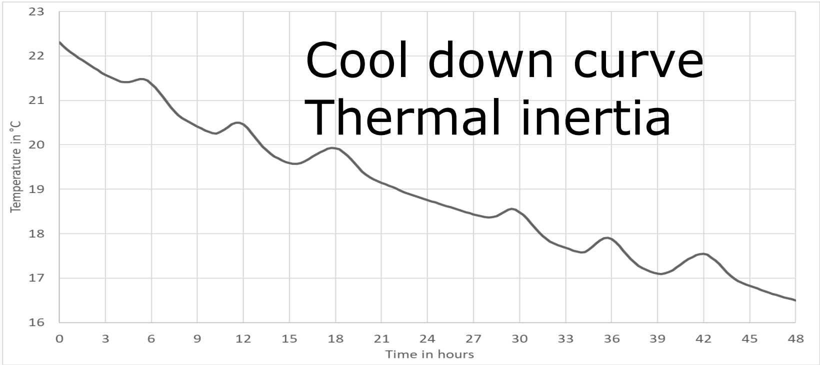
Appendix



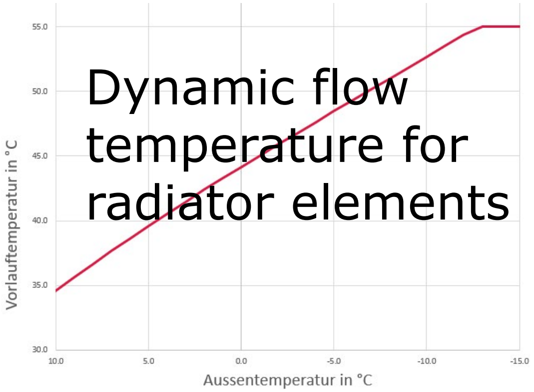
↑ Dynamic COP and thermal capacity



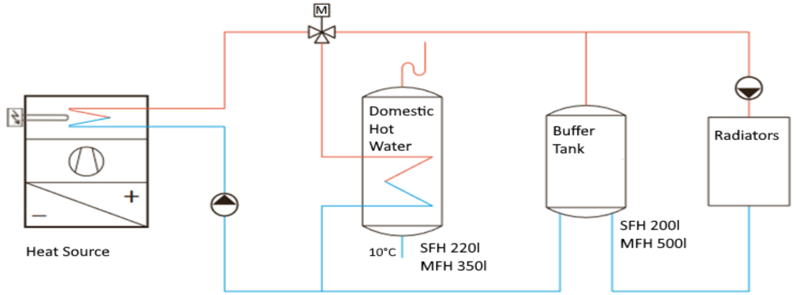
← Simulations in IDA ICE



Cool down curve
Thermal inertia



Dynamic flow temperature for radiator elements



← System configuration and dimensioning