Mitigating space heat demand peaks in buildings in a highly renewable European energy system

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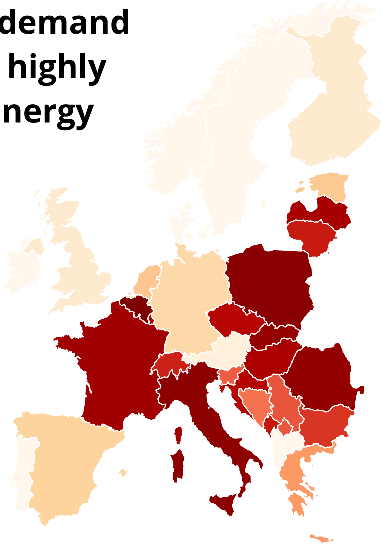

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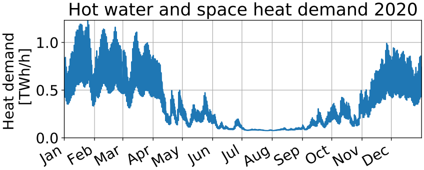
Challenge heat demand peaks in highly renewable energy systems

- heating sector accounts for about **40%** of total CO_2 emissions in Europe and thus play a key role in reducing overall costs and greenhouse gas emissions
- many scenarios to reach net-zero emissions in buildings rely on **electrification**

Challenge

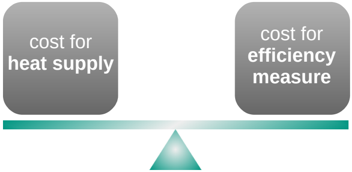
→ both demand and supply **depend on weather**
→ heat demand is **seasonal**, capacities are only needed for a part of the year



How can we cost-effective mitigate heat demand peaks?

Research questions

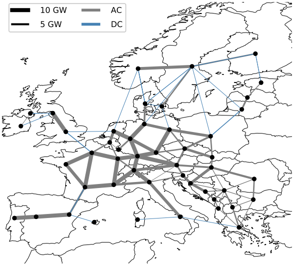
- how do heat demand peaks influence cost and design of a highly-renewable European energy system?
- which instruments are most suitable to mitigate these heat demand peaks?



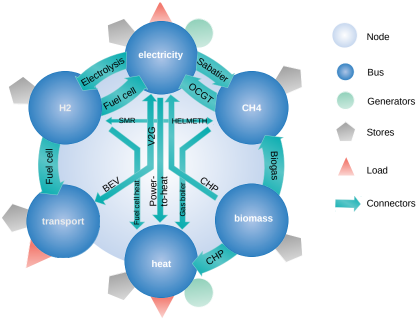
co-optimising energy supply and efficiency measures all over **Europe** with **high temporal resolution**

Sector-coupling model PyPSA-Eur-Sec

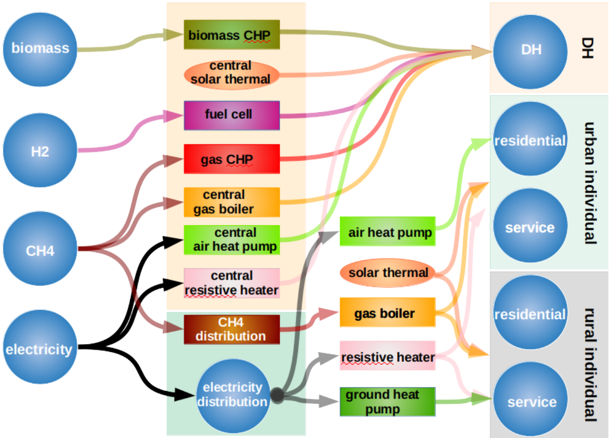
covering all of Europe with hourly resolution



including demands land transport, heat for buildings and electricity



Heat supply



CHP: Combined Heat and Power plant, CH4: methane, DH: District Heating

Energy System Optimisation

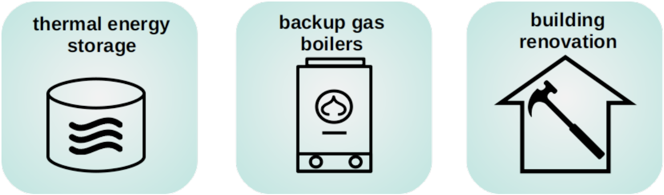
Find the cost-optimal energy configuration that consists of the operational costs and a fixed generation and storage fleet

$$\min \begin{pmatrix} \textbf{total} \\ \textbf{system} \\ \textbf{costs} \end{pmatrix} = \min \left(\sum_{\substack{\text{nodes,} \\ \text{techs,} \\ \text{time}}} \begin{pmatrix} \textbf{operational} \\ \textbf{costs} \end{pmatrix} + \sum_{\substack{\text{nodes} \backslash \text{lines} \\ \text{techs}}} \begin{pmatrix} \textbf{annualised} \\ \textbf{capital costs} \end{pmatrix} \right)$$

The "total system" covers an **hourly** resolved time frame of **one distinct year**. CO_2 emissions are constraint to be **net-zero**.

Instruments to mitigate space heat demand peaks

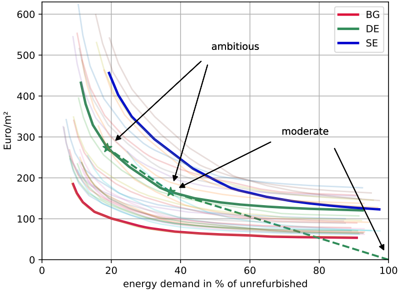
analyse individual and combined effects of the three instruments



- thermal energy storage in form of water tanks
  (2 different types: short- and long-term)
- hybrid heating: gas boilers as backup for heat pumps
- building renovation by additional insulation material and replacing energy inefficient windows

Modelling building renovation on a large scale

country-specific building stock characteristic (age, insulation state, building types)



(1) Determine energy-cost curves for each country and sector

Space heat demand E_{space}

$$E_{\text{space}} = \Phi_{\text{loss}} - \nu \cdot \Phi_{\text{gain}}.$$

Costs for renovation measures c_{retro} with additional insulation δl

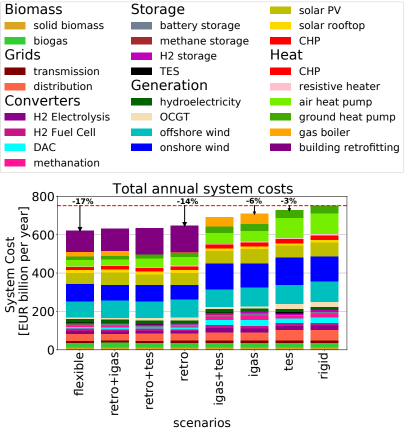
$$c_{\text{retro}}(\delta l) = \sum_e \left(c_{e,\text{fix}} + \delta l_e \cdot c_{e,\text{var}}\right) + c_{\text{window}}.$$

(2) add two renovation measures with linear relation between costs and heat demand reduction

8 possible combinations of the 3 balancing tools

scenario	building retrofitting	thermal energy storage (tes)	individual gas boilers
flexible	✓	✓	✓
retro+igas	✓	✗	✓
retro+tes	✓	✓	✗
retro	✓	✗	✗
igas+tes	✗	✓	✓
igas	✗	✗	✓
tes	✗	✓	✗
rigid	✗	✗	✗

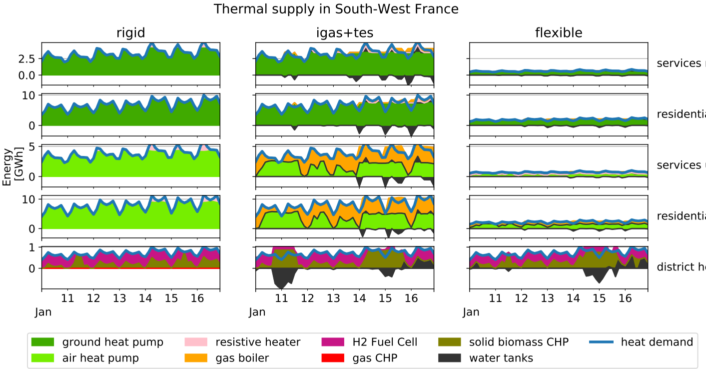
Results - Total system costs



- balancing instruments reduce overall costs by up to 17%
- most cost-effective is building renovation (4 scenarios in the left)
- if building retrofitting is in place, gas distribution could be removed without significantly higher costs
- use of mitigating tools can avoid public acceptance problems, as less generation, storage and transmission capacity is needed

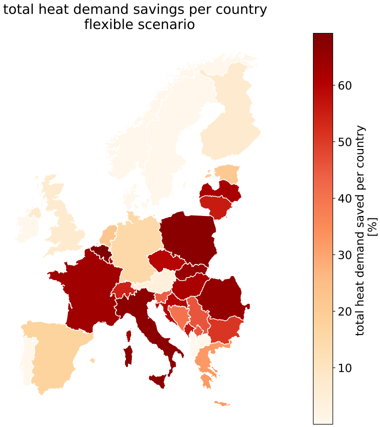
Results - Thermal supply example week

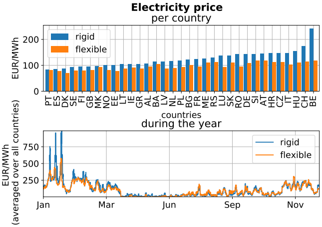
- backup gas boilers are used at peak demands
- high efficiency measures in individual heating systems



Results - Building renovation

cost-optimal solution includes building renovations to save an average of 44-51% of space heat depending on the country





Heat savings depend on the combination of **both** the country-specific costs for renovation and the costs for energy supply during the heating season

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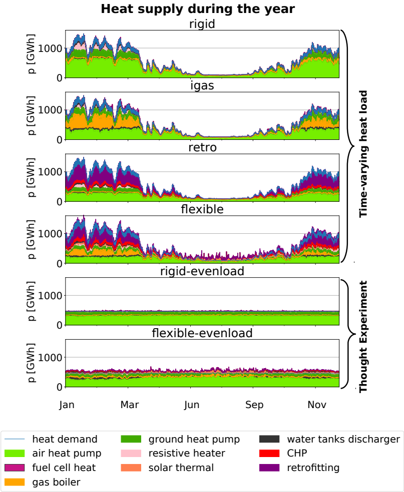
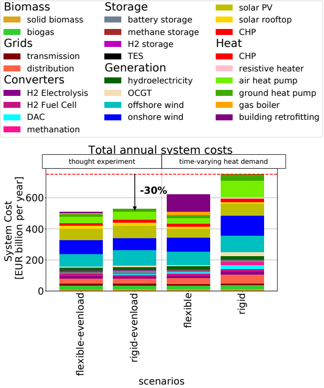
Results - Thought experiment constant heat load



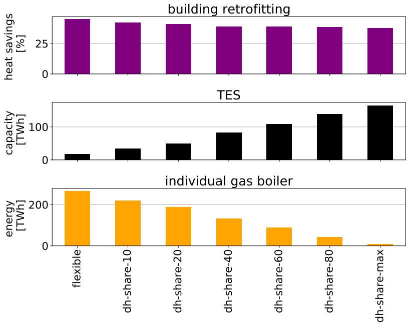
nearly no building renovation with constant heat demand
→ **need to mitigate heat peaks and not overall energy consumption**



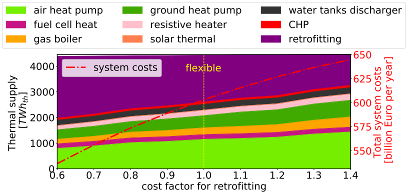
Sensitivity

vary scenario assumptions (distribution costs, grid expansion, weather years, cost for renovation, district heating share, sink temperature of heat pumps, restrict wind potential)

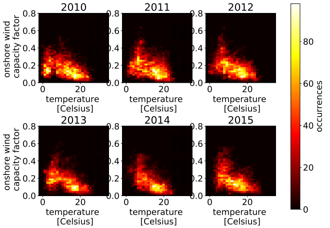
increase district heating



various costs for retrofitting

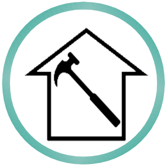


different weather years



Conclusion

up to **30% of total system costs** are caused by seasonal heat demand peaks



building **renovation** enables largest cost reductions of up to **14%**

with efficiency improvements, all gas **distribution** to buildings **can be excluded** with only 1-2% higher costs

investments in energy efficiency in buildings are driven by **need to reduce peak demand, not overall energy consumption**

Link to the full paper

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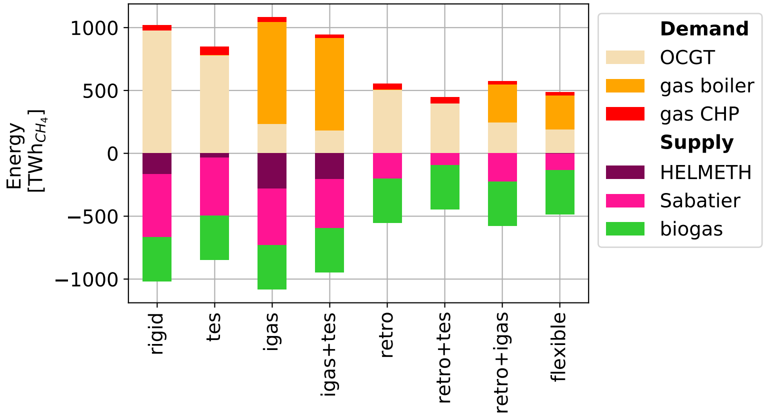
Gas balance



Energy [TWh$_{CH_4}$]
1000
500
0
−500
−1000
rigid
tes
igas
igas+tes
retro
retro+tes
retro+igas
flexible
Demand
OCGT
gas boiler
gas CHP
Supply
HELMETH
Sabatier
biogas

Sensitivity - restrict wind potential