4th International Workshop on Carnot Batteries
23-25 September 2024

Comparative and prospective life cycle assessment of residential Carnot batteries

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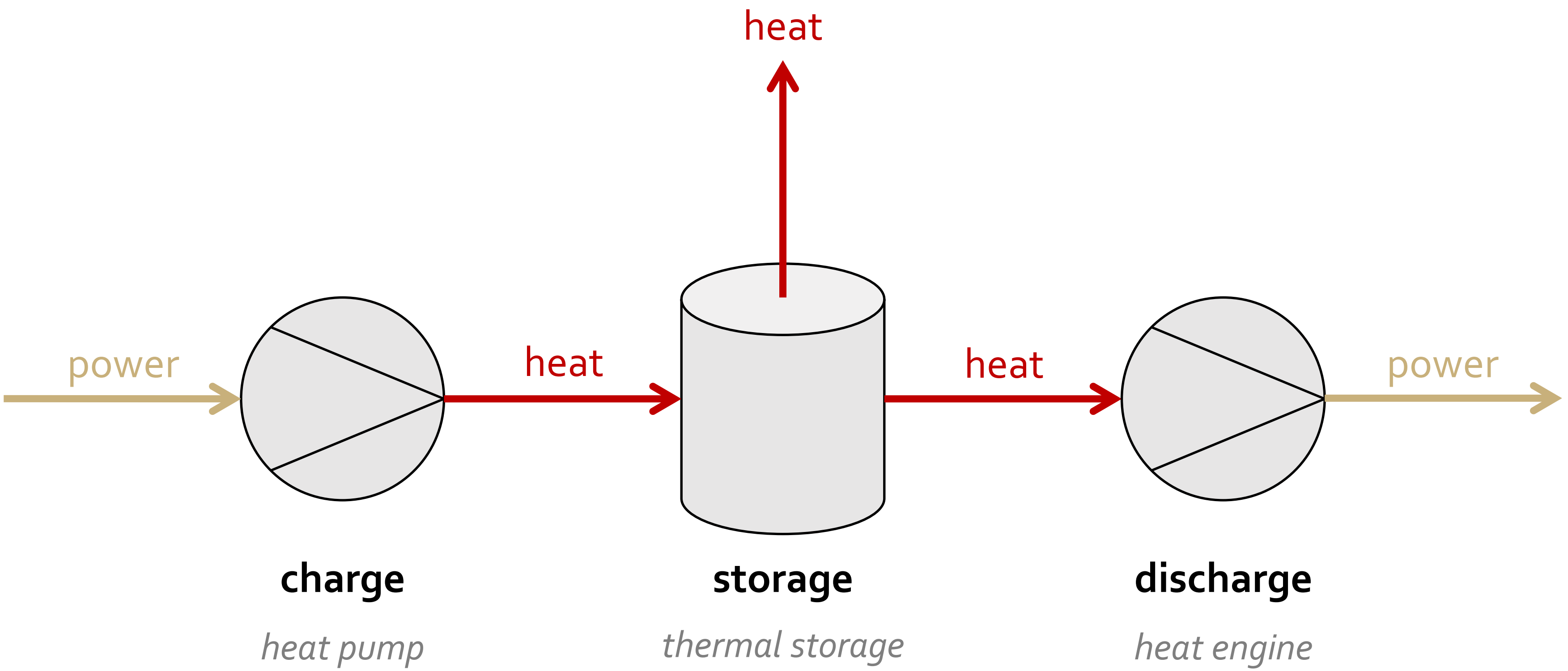
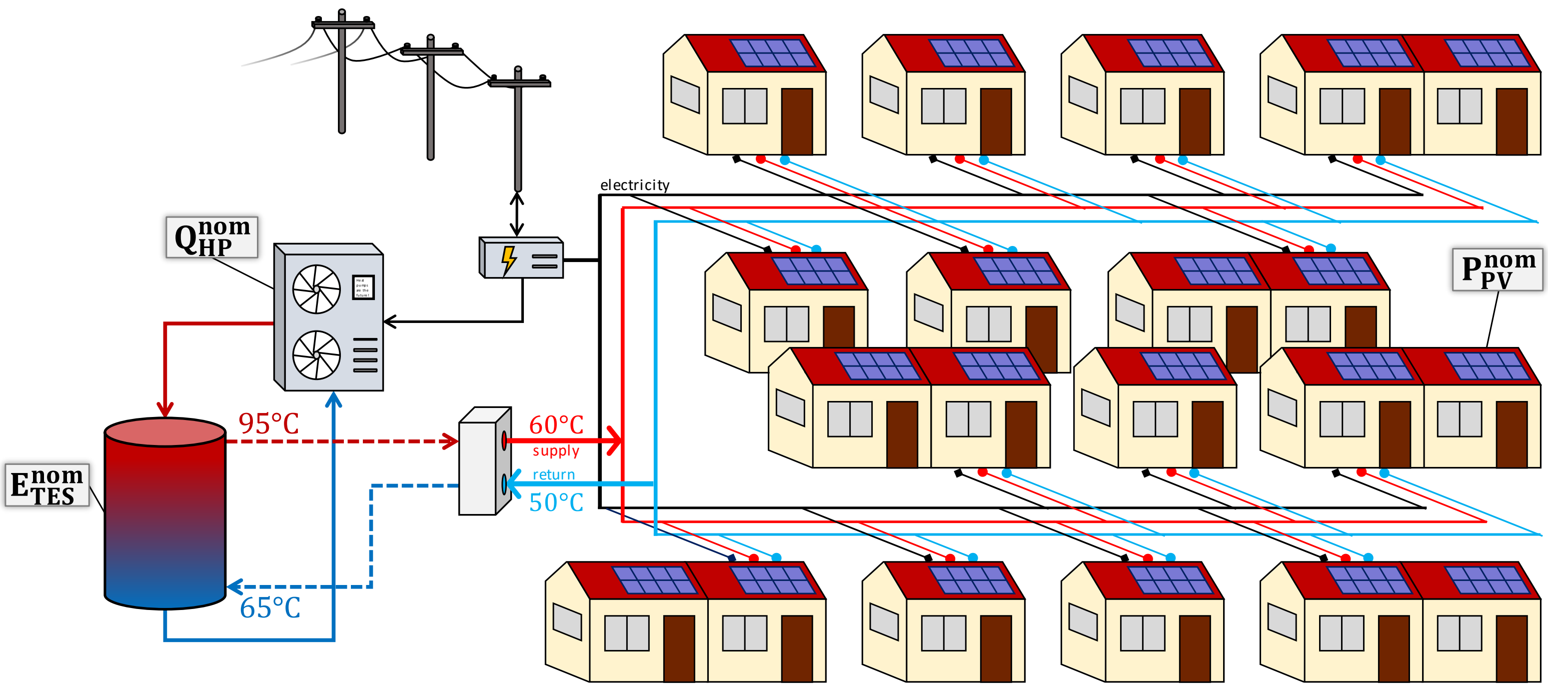
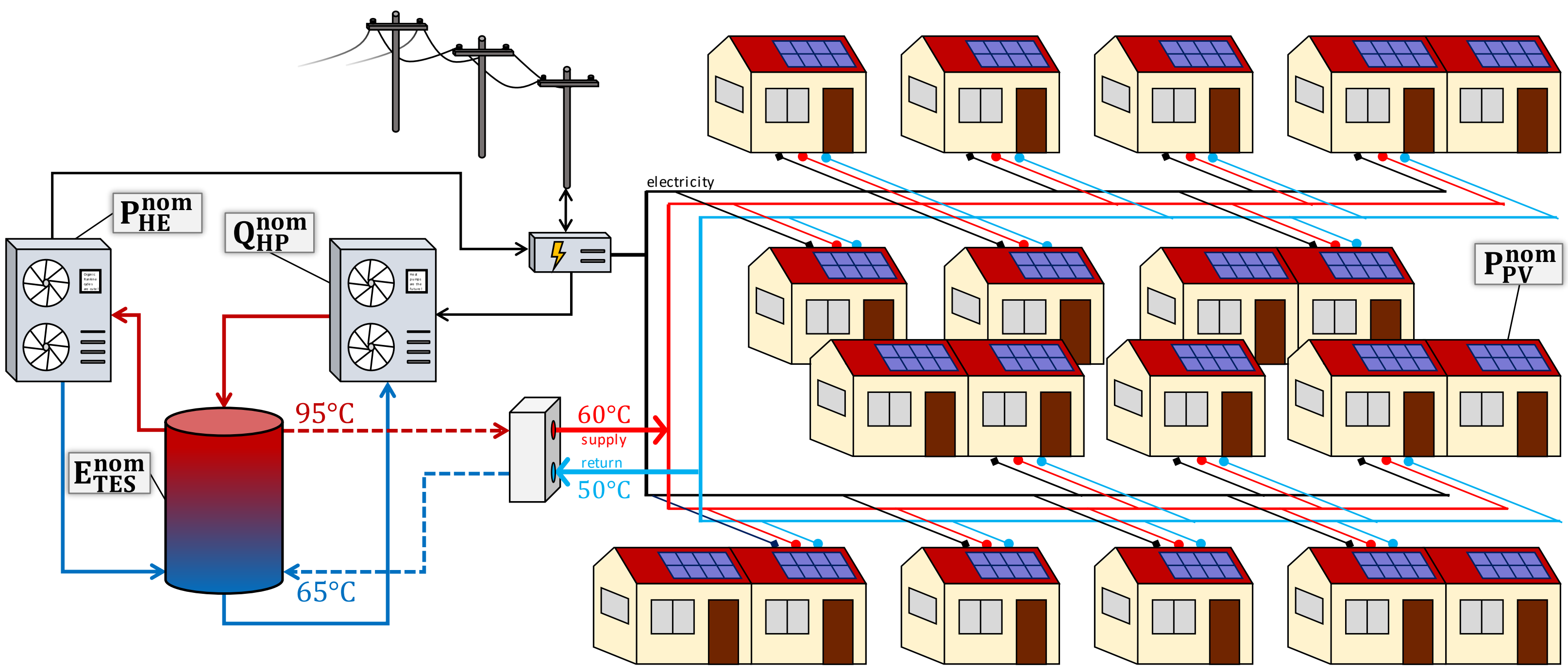
Carnot batteries for heat and power management



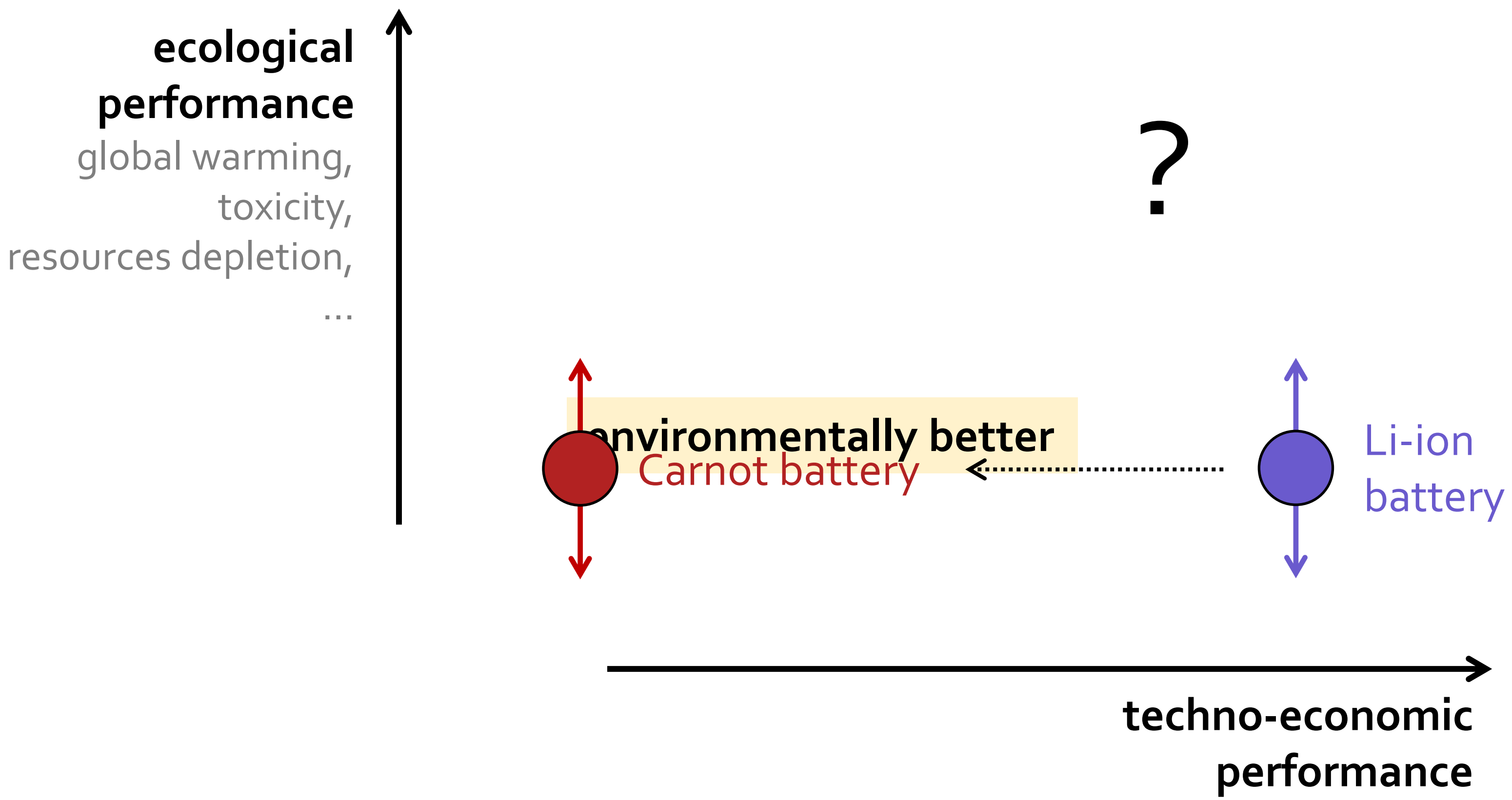
Potential application is residential (coupling with photovoltaic)



Adding a heat engine provides an electrical storage capacity



Are Carnot batteries really cleaner than Li-ion batteries?



Could Carnot batteries be better for the environment than Li-ion batteries in residential applications?

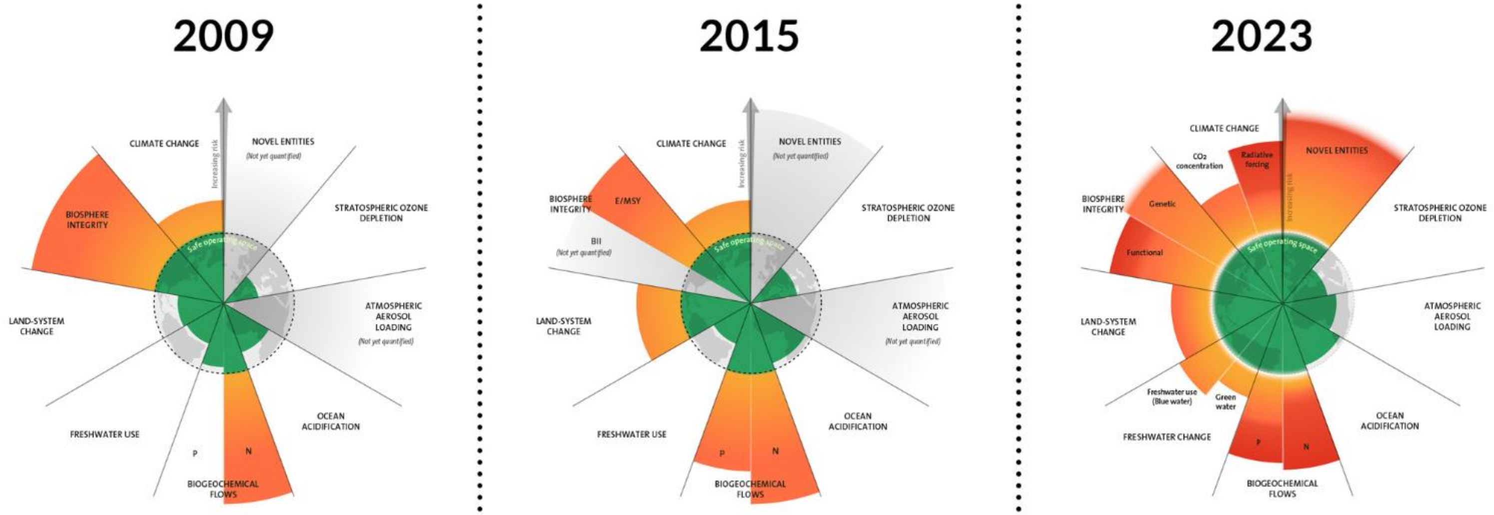
Short answer…

Best design: right mix between **Carnot battery** and **Li-ion battery**

Carnot battery has lower impact on natural resources;

However, not a game changer: impact is driven by photovoltaic system and grid

Let's observe several criteria to not fall into the carbon tunnel



7 boundaries assessed, 3 crossed	7 boundaries assessed, 4 crossed	9 boundaries assessed, 6 crossed

Stockholm Resilience Centre

Comparative and prospective Life-Cycle Assessment (LCA)

Goal and Scope Definition

↓

Life Cycle Inventory (LCI)

↓

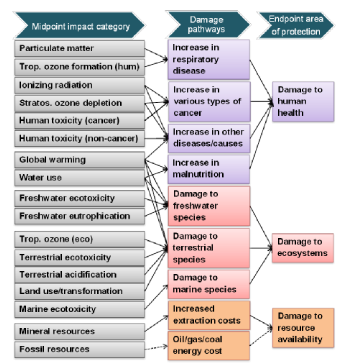
Life Cycle Impact Assessment (LCIA)

LCI database : ecoinvent 3.10 + litterature

Wernet et al., 2016

LCIA method: ReCiPe 2016 v1.03 (H)

Huijbregts et al., 2016



software: Activity Browser (Brightway)

Steubing et al., 2020

Mutel, 2017

Comparative and prospective Life-Cycle Assessment (LCA)

Goal and Scope Definition

Life Cycle Inventory (LCI)

Life Cycle Impact Assessment (LCIA)

Goal Assess whether Carnot batteries can reduce the environmental footprint of residential energy systems compared with chemical batteries

Scope *System boundaries:* Cradle-to-Grave (raw materials to end-of-life)

Functional unit: annual supply of heat and electricity for a housing development of 20 dwellings

Six different system topologies have been considered

Goal and Scope Definition

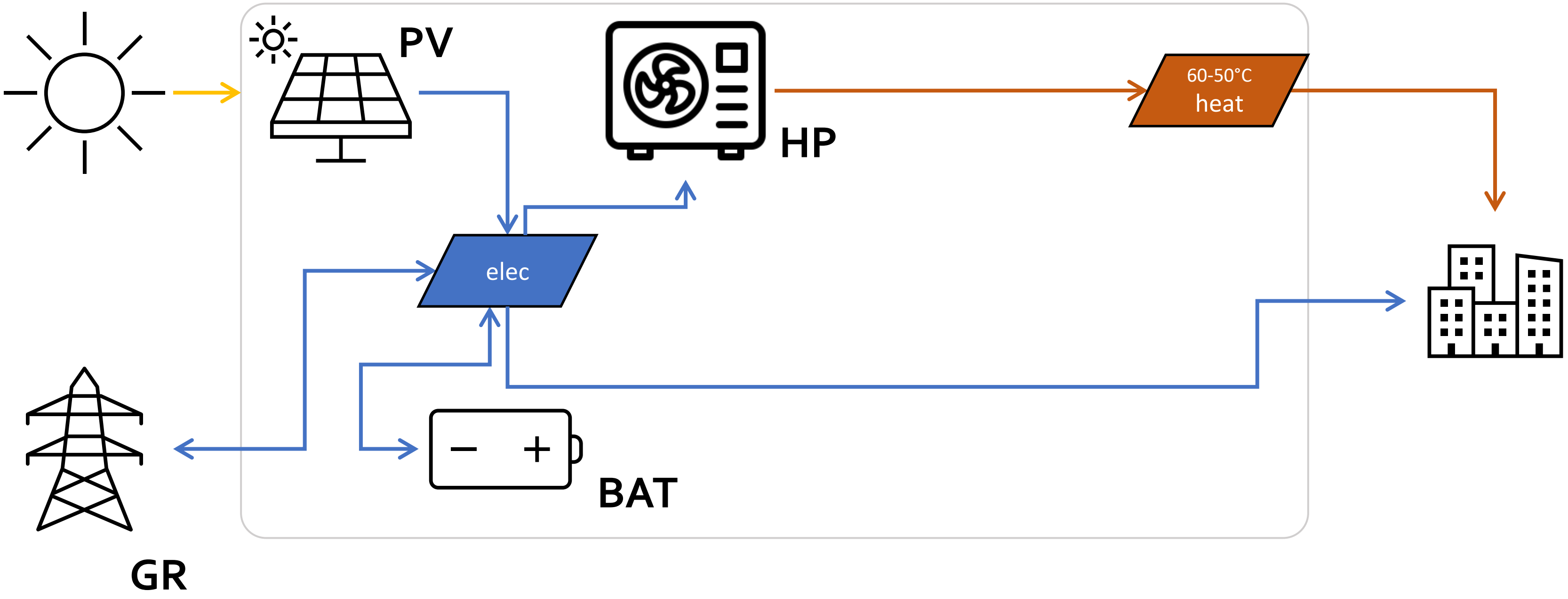
Life Cycle Inventory (LCI)

Life Cycle Impact Assessment (LCIA)

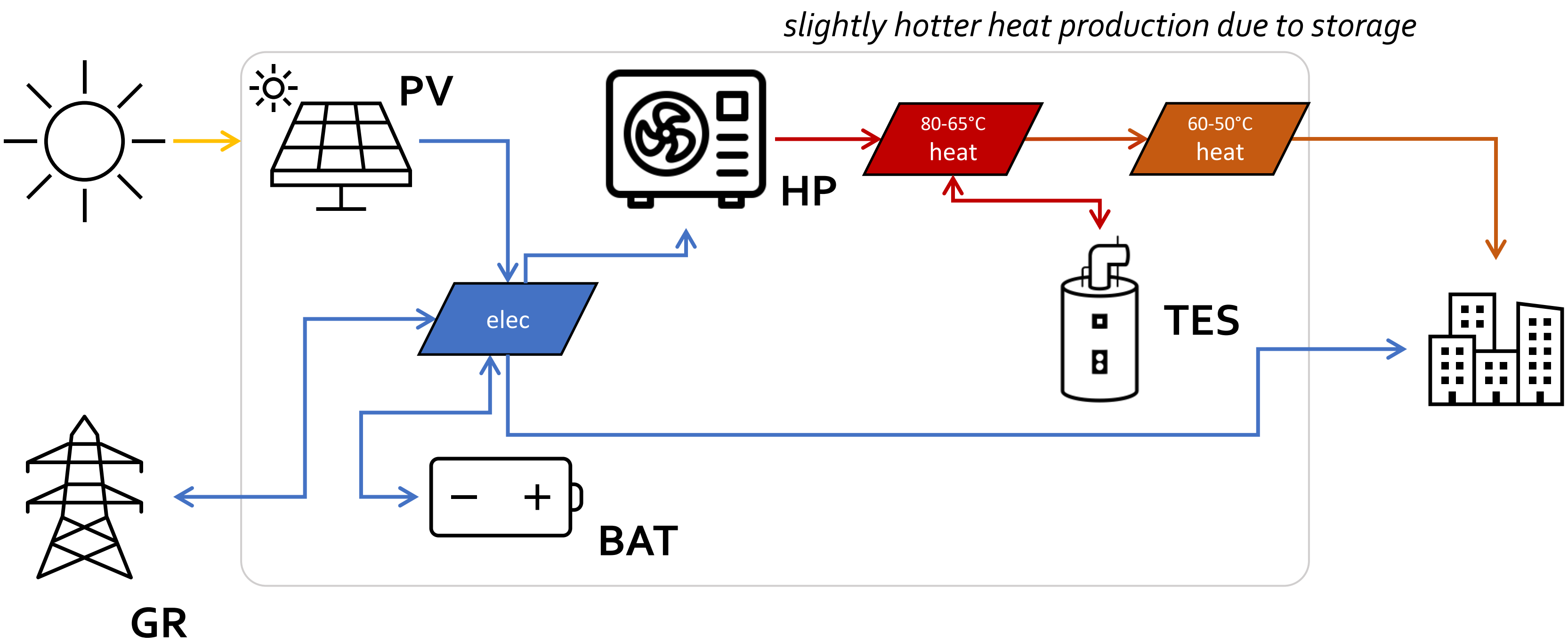
Design Different system topologies are considered:

- *Li-ion battery vs Carnot battery;*
- *Storage temperature;*
- *Hybrid configurations;*
- *...*

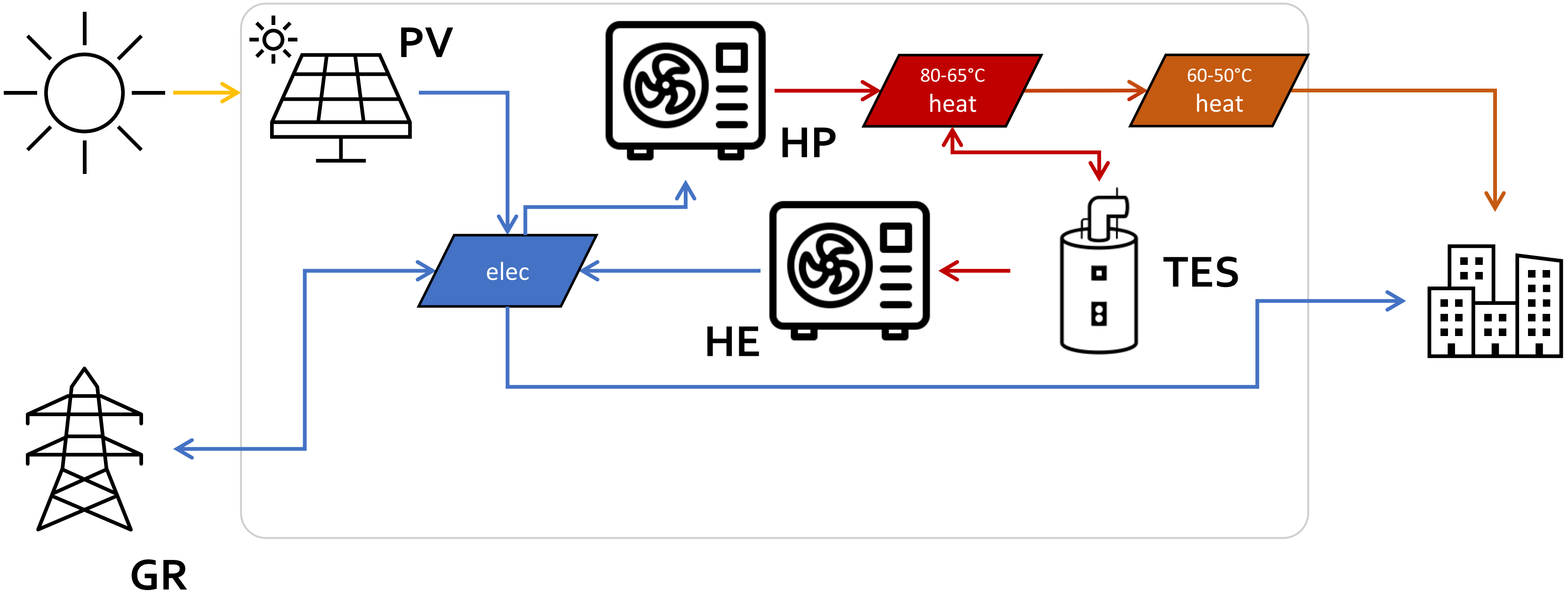
PV + HP + BAT (60°C)



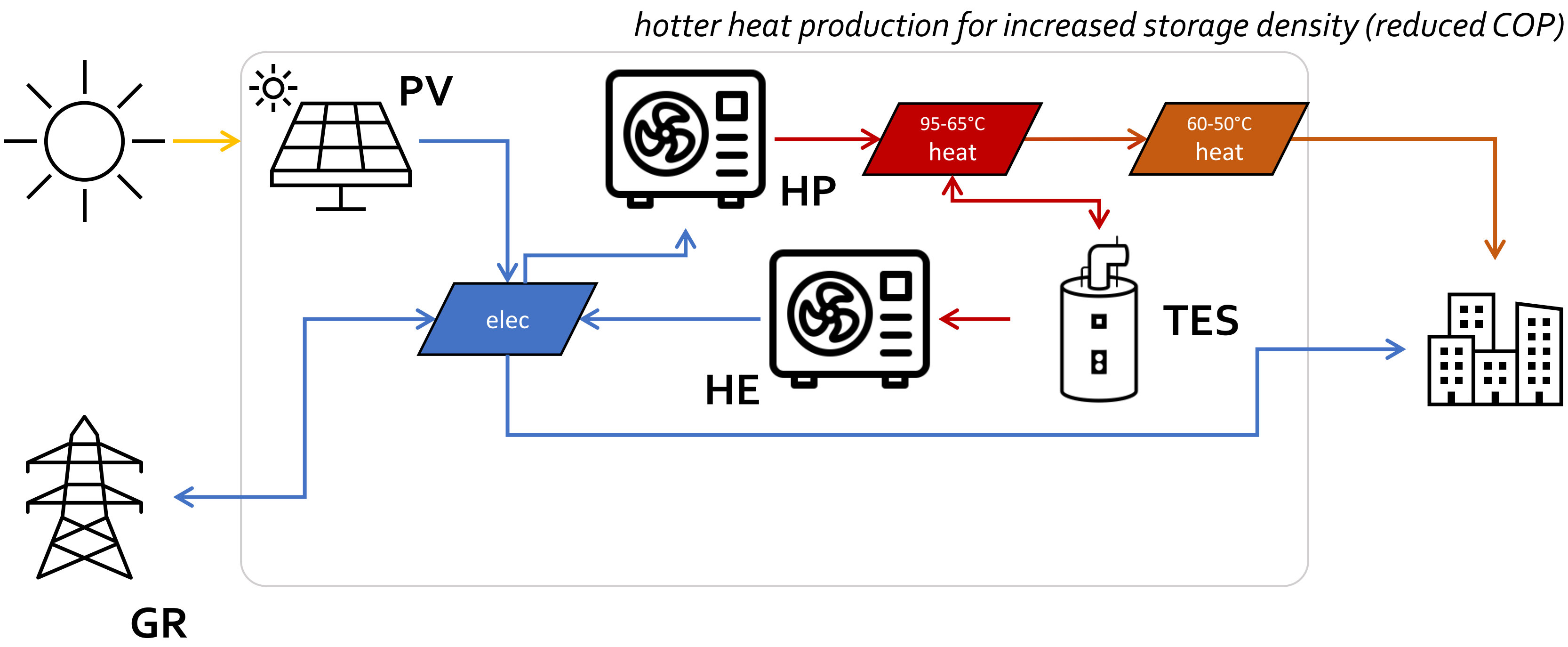
PV + HP + BAT + TES (80°C)



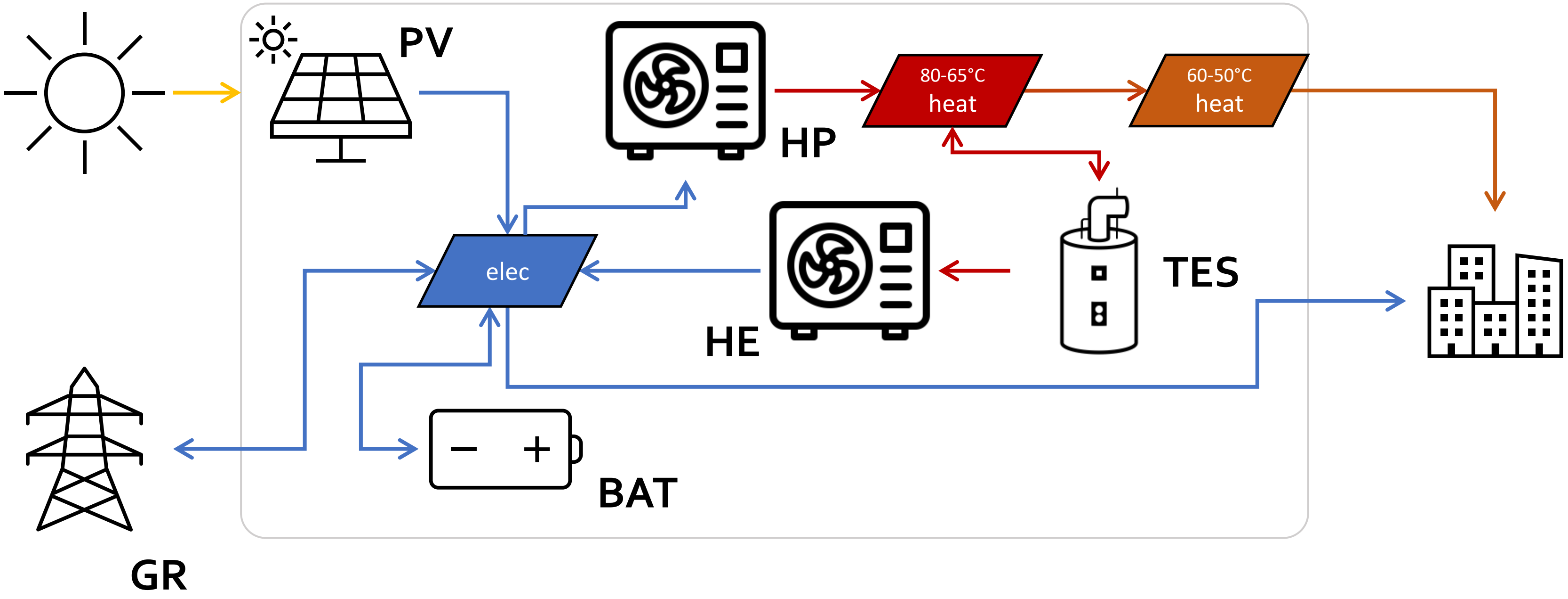
PV + HP + TES + HE (80°C)



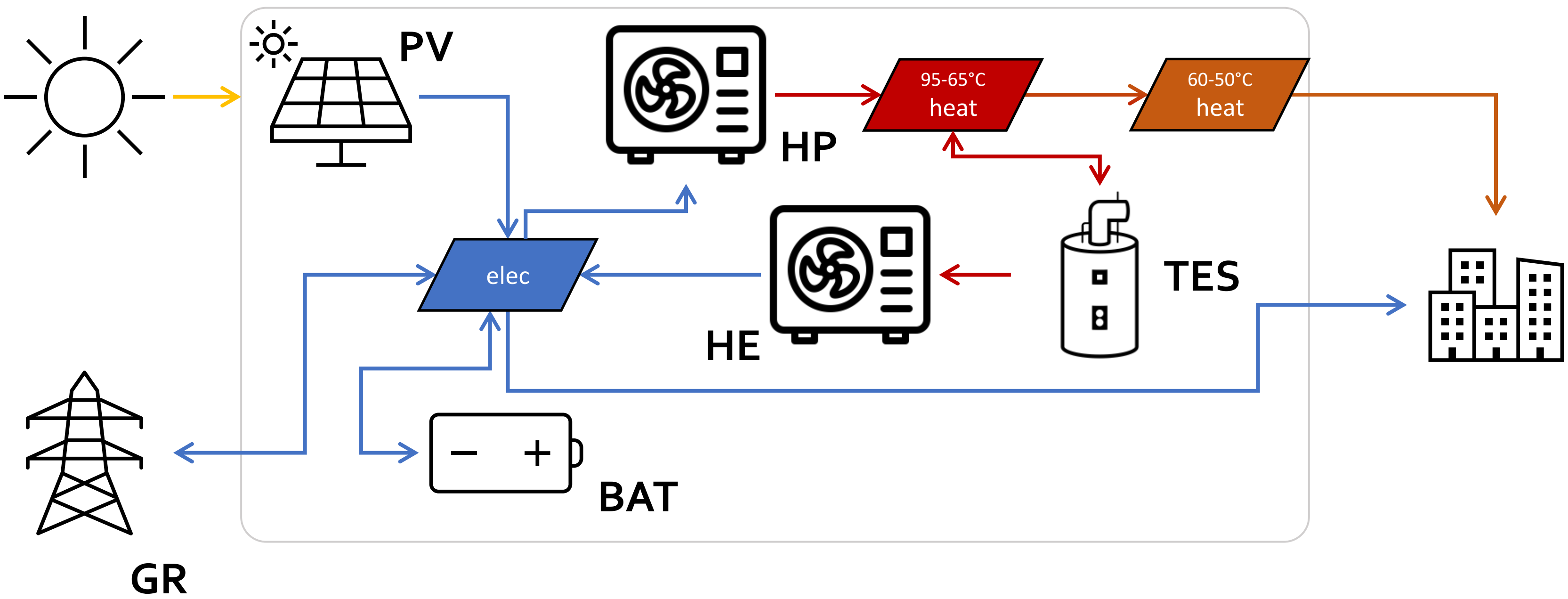
PV + HP + TES + HE (95°C)



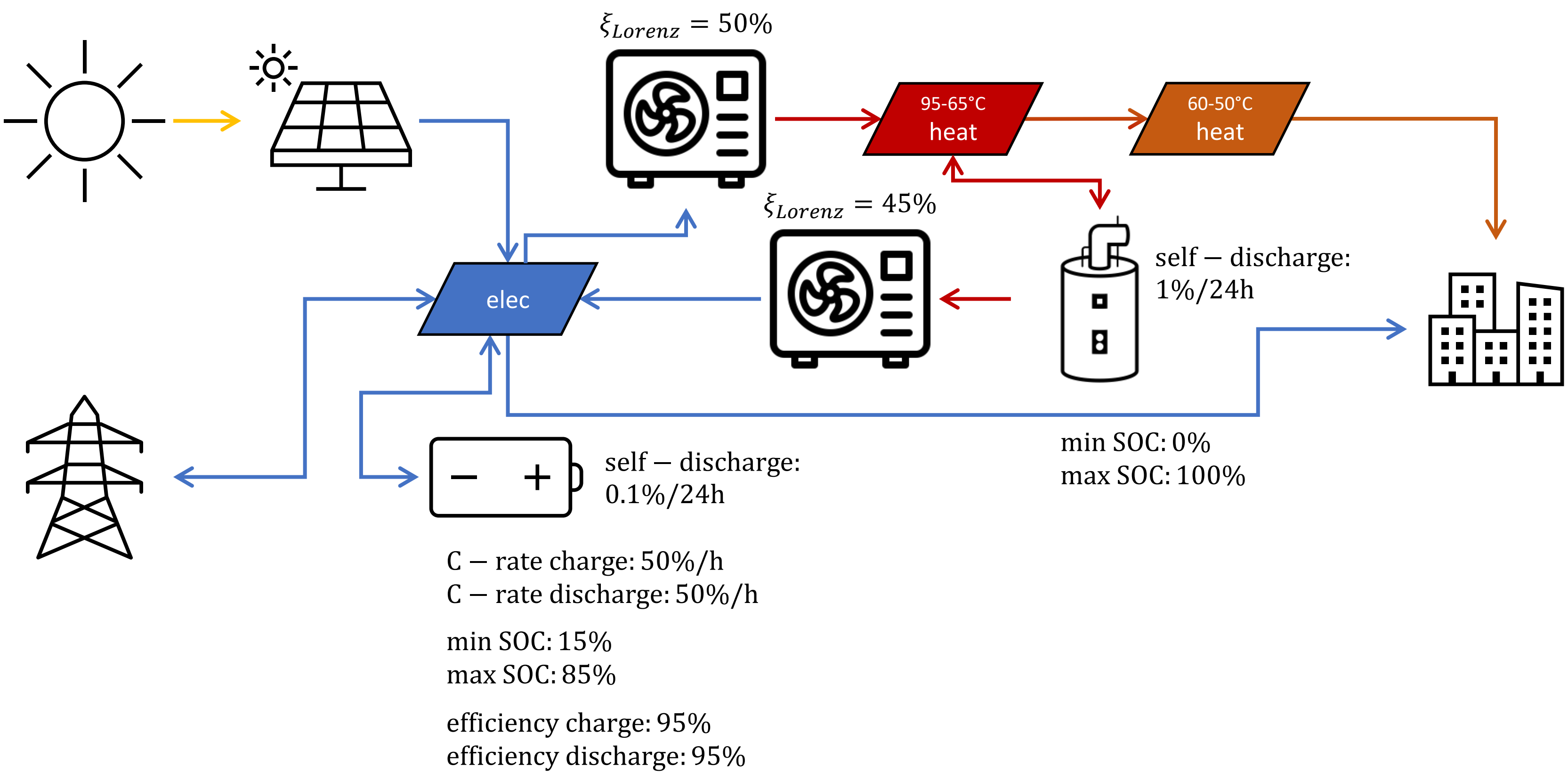
PV + HP + BAT + TES + HE (80°C)



PV + HP + BAT + TES + HE (95°C)



Linear Programming for optimum system design and operations



Boundary conditions with hourly resolution (Pisa)

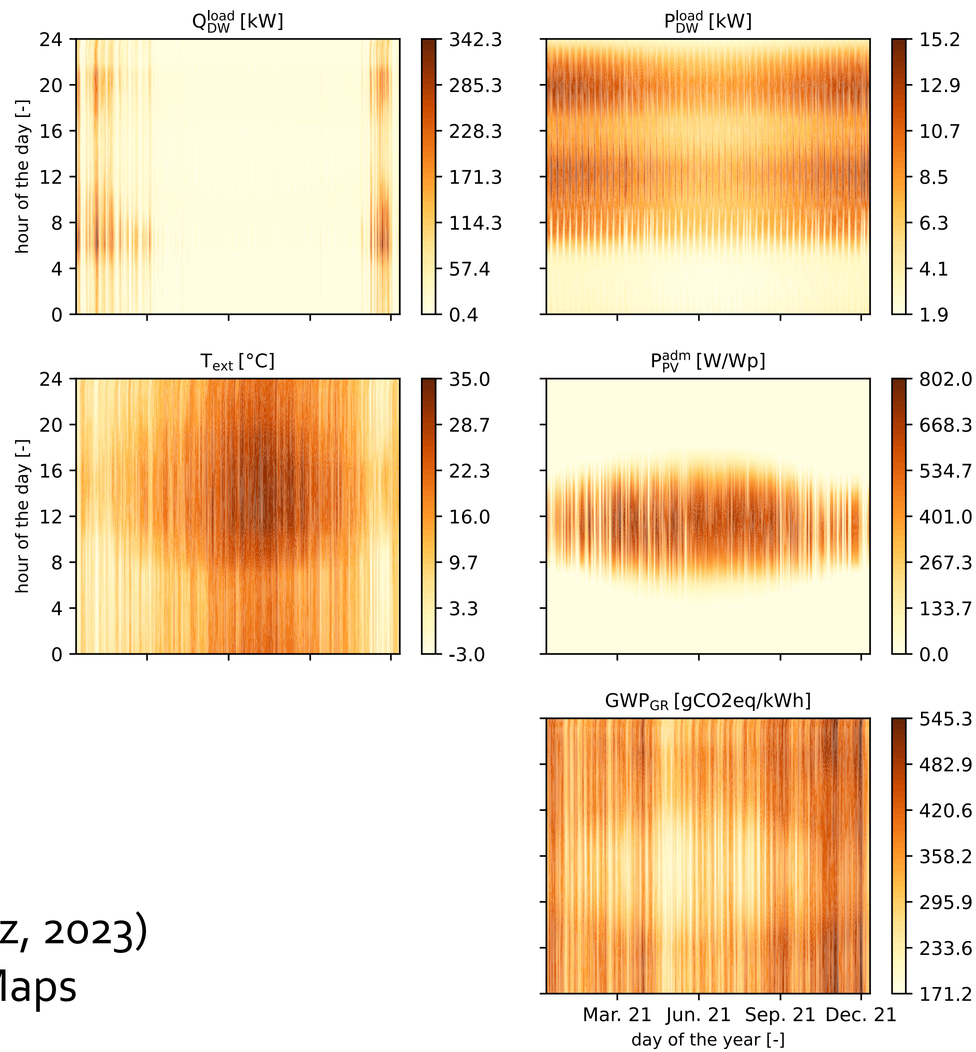
total thermal load

electrical load

external temperature

solar irradiance

carbon intensity of grid electricity



From nPro (Wirtz, 2023) and Electricity Maps

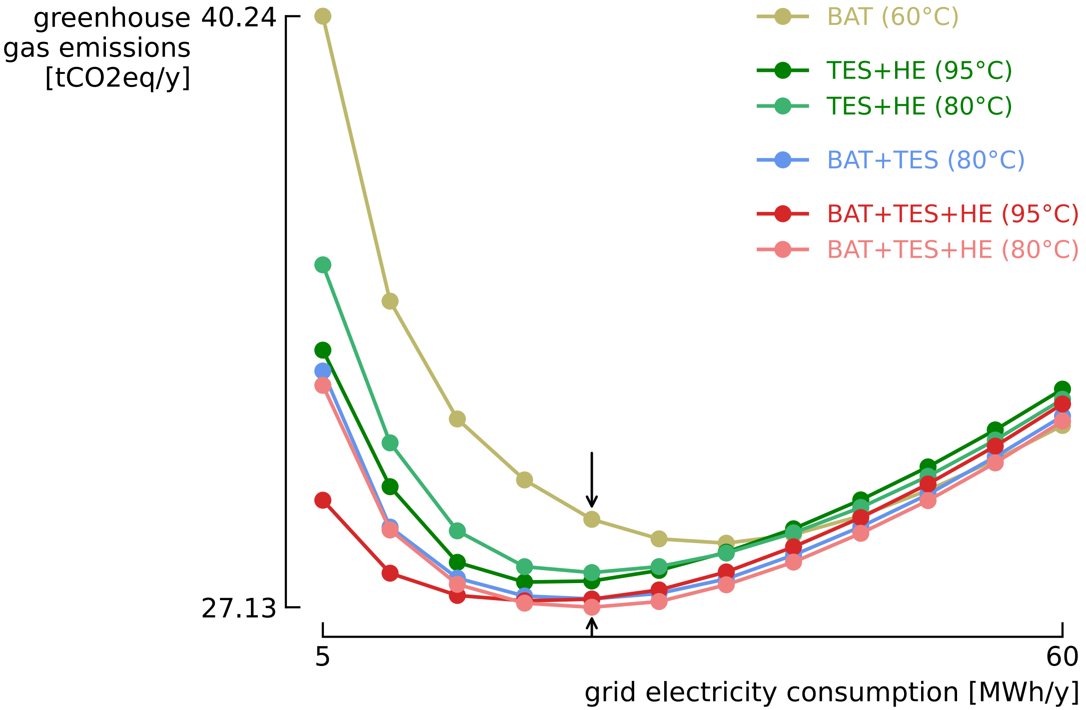
Systems are designed to minimise greenhouse gas emissions

Goal and Scope Definition

Life Cycle Inventory (LCI)

Life Cycle Impact Assessment (LCIA)

For fair comparison, each topology provides **same consumption of grid electricity** (i.e. self-sufficiency)

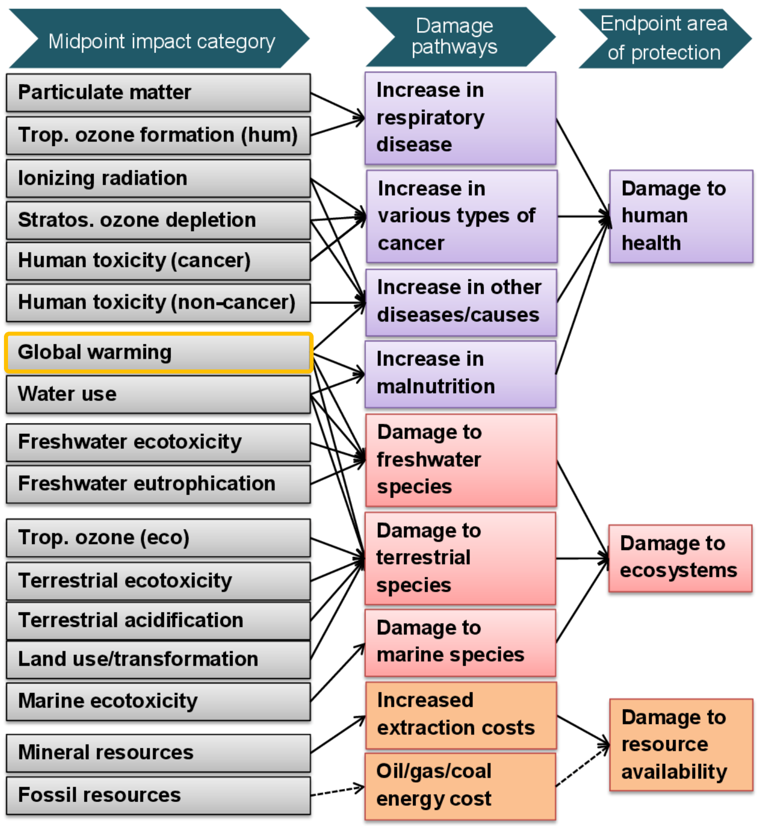


Focus first on global warming midpoint, then look at others

Goal and Scope Definition

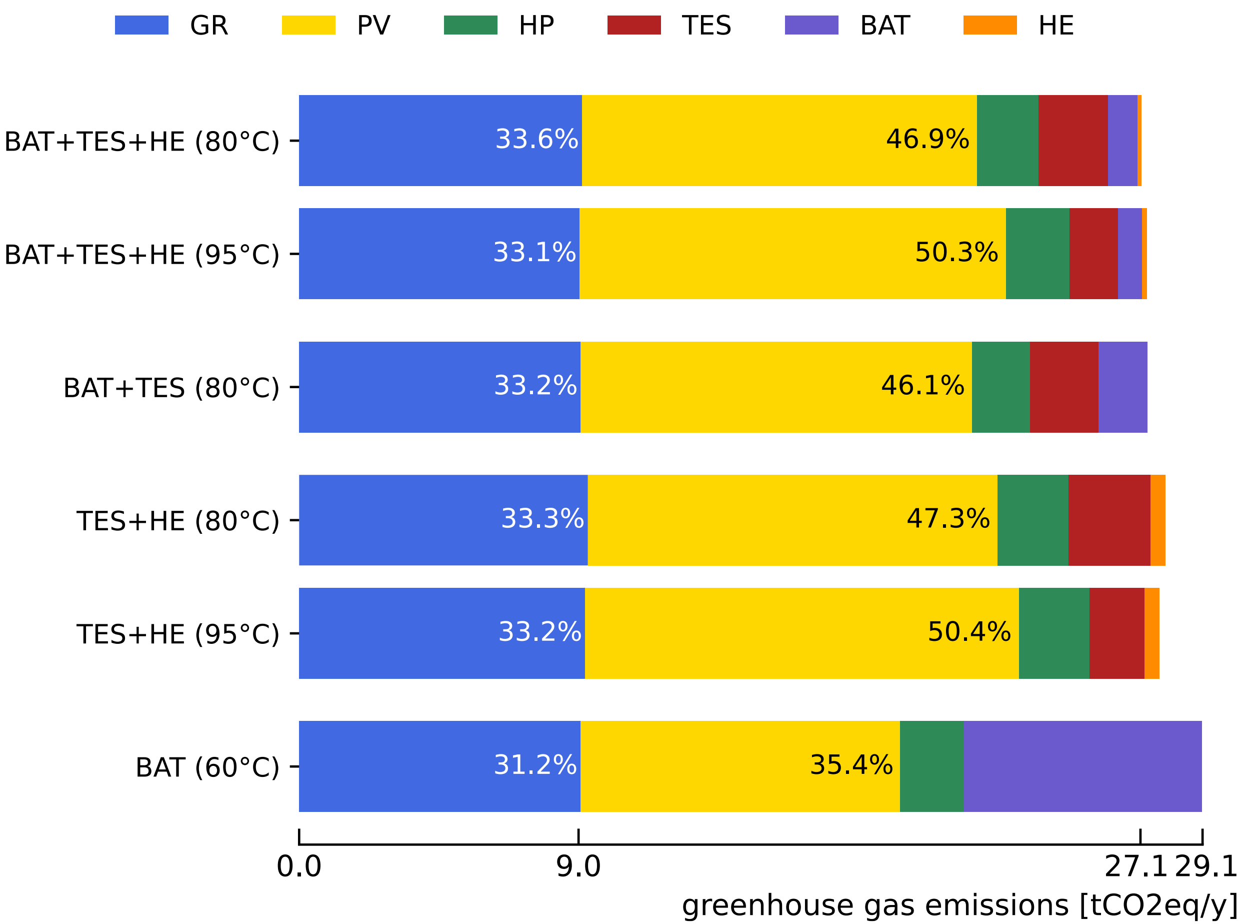
Life Cycle Inventory (LCI)

Life Cycle Impact Assessment (LCIA)

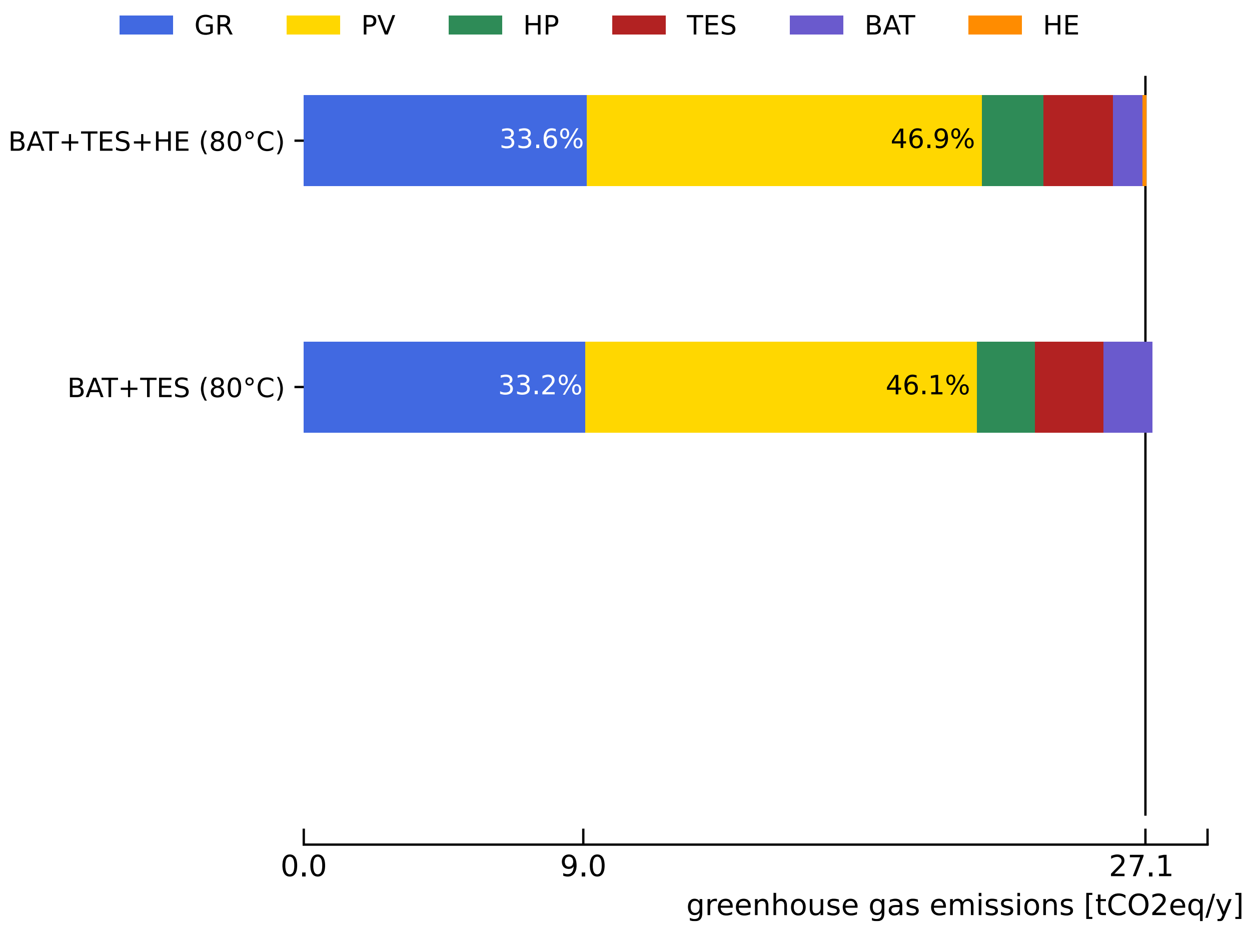


Huijbregts et al., 2016

PV is by far the first source of GHG emissions, GR is second



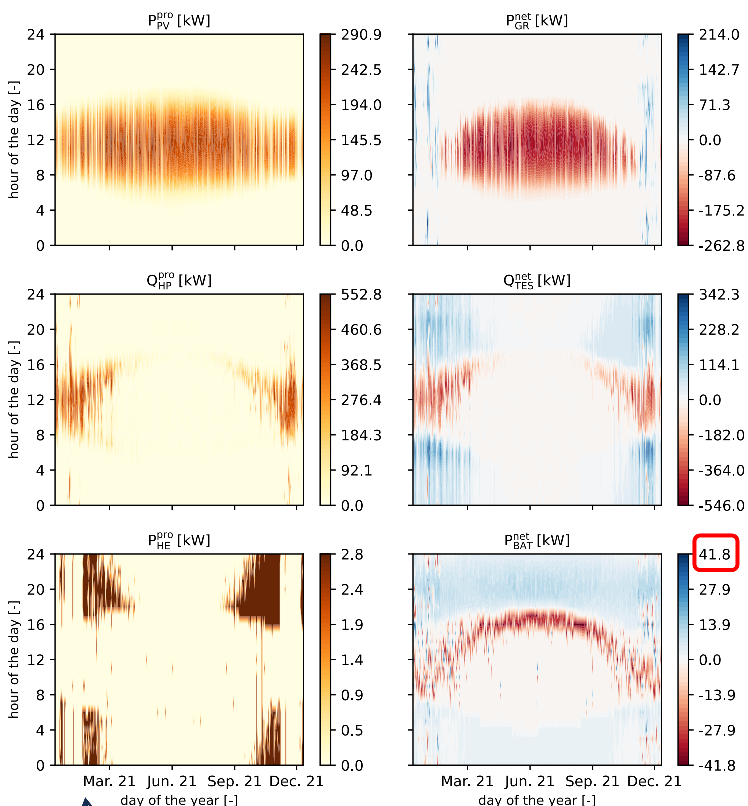
Best design contains BAT + HE, but these play different roles



Operation maps illustrate BAT downsizing (-40%) thanks to HE

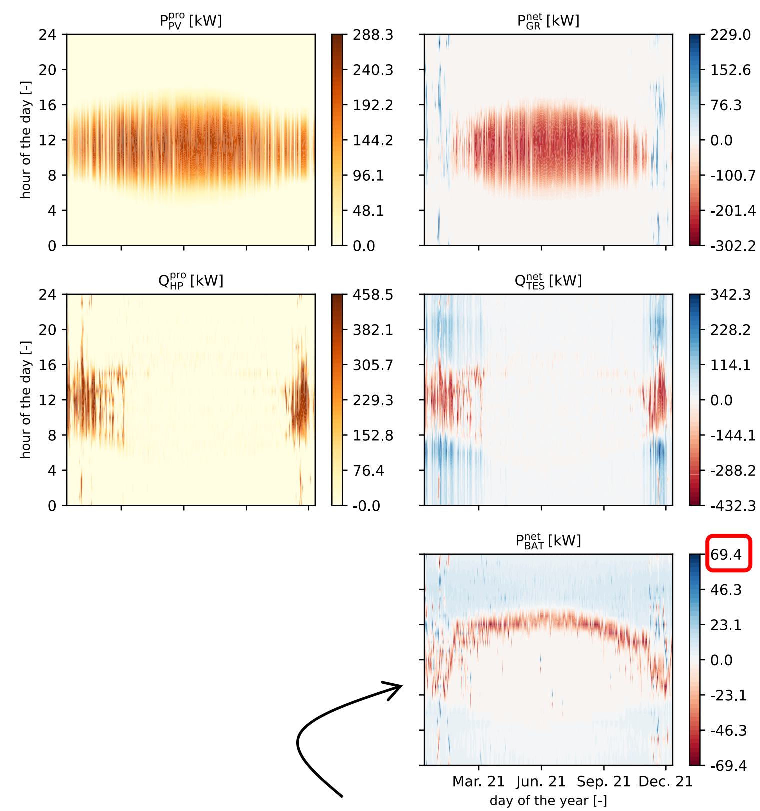
BAT+TES+HE (80°C)

COP: 2.7
ETA: 7.5%



BAT+TES (80°C)

COP: 2.6



BAT for daily storage, all year long (remaining 89%)

HE for morning and evening peaks, in autumn and winter (11% of storage)

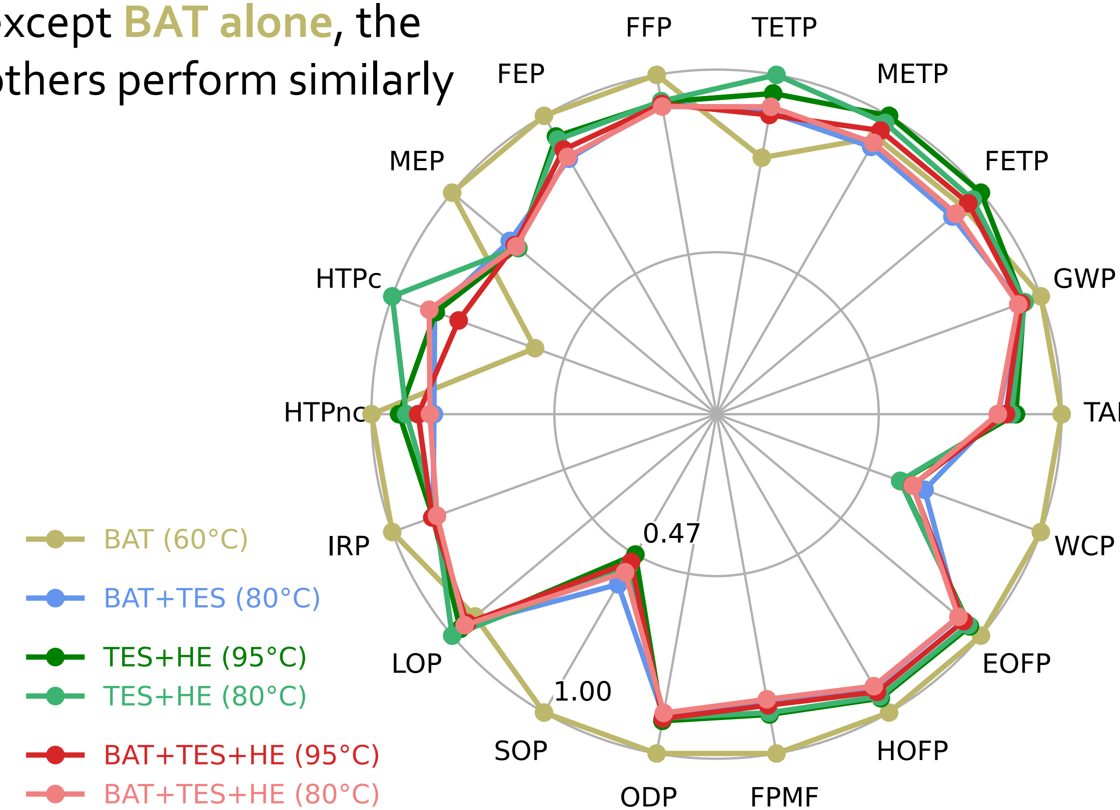
18 midpoints: no evident winner between CB and BAT

Goal and Scope Definition

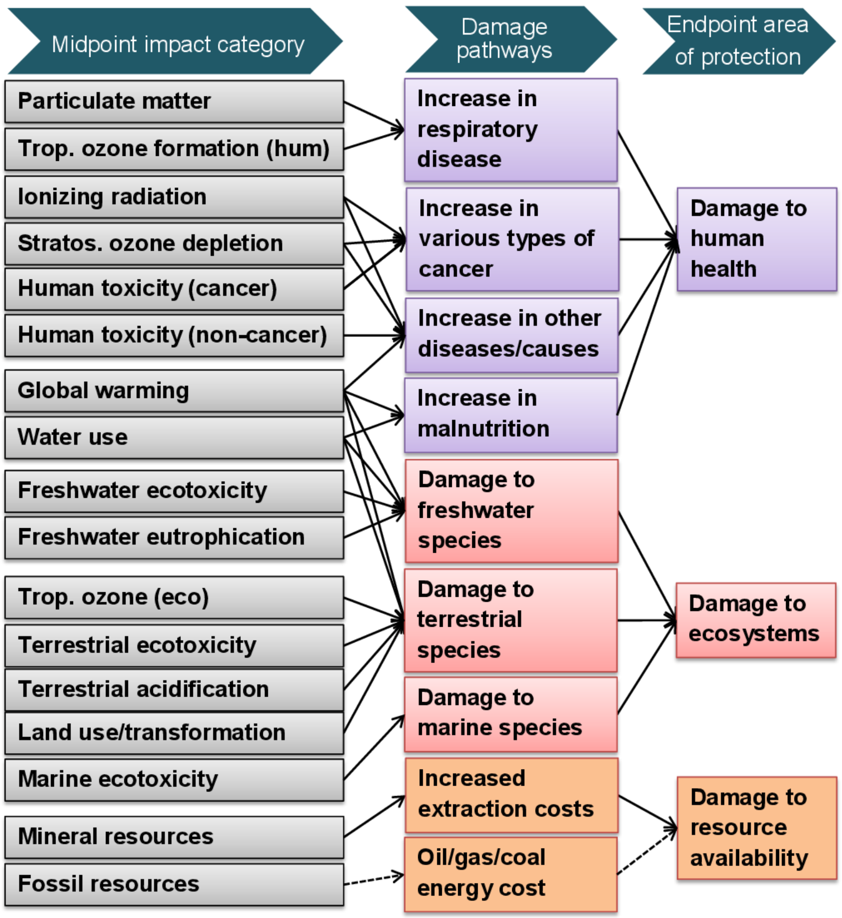
Life Cycle Inventory (LCI)

Life Cycle Impact Assessment (LCIA)

except **BAT alone**, the others perform similarly

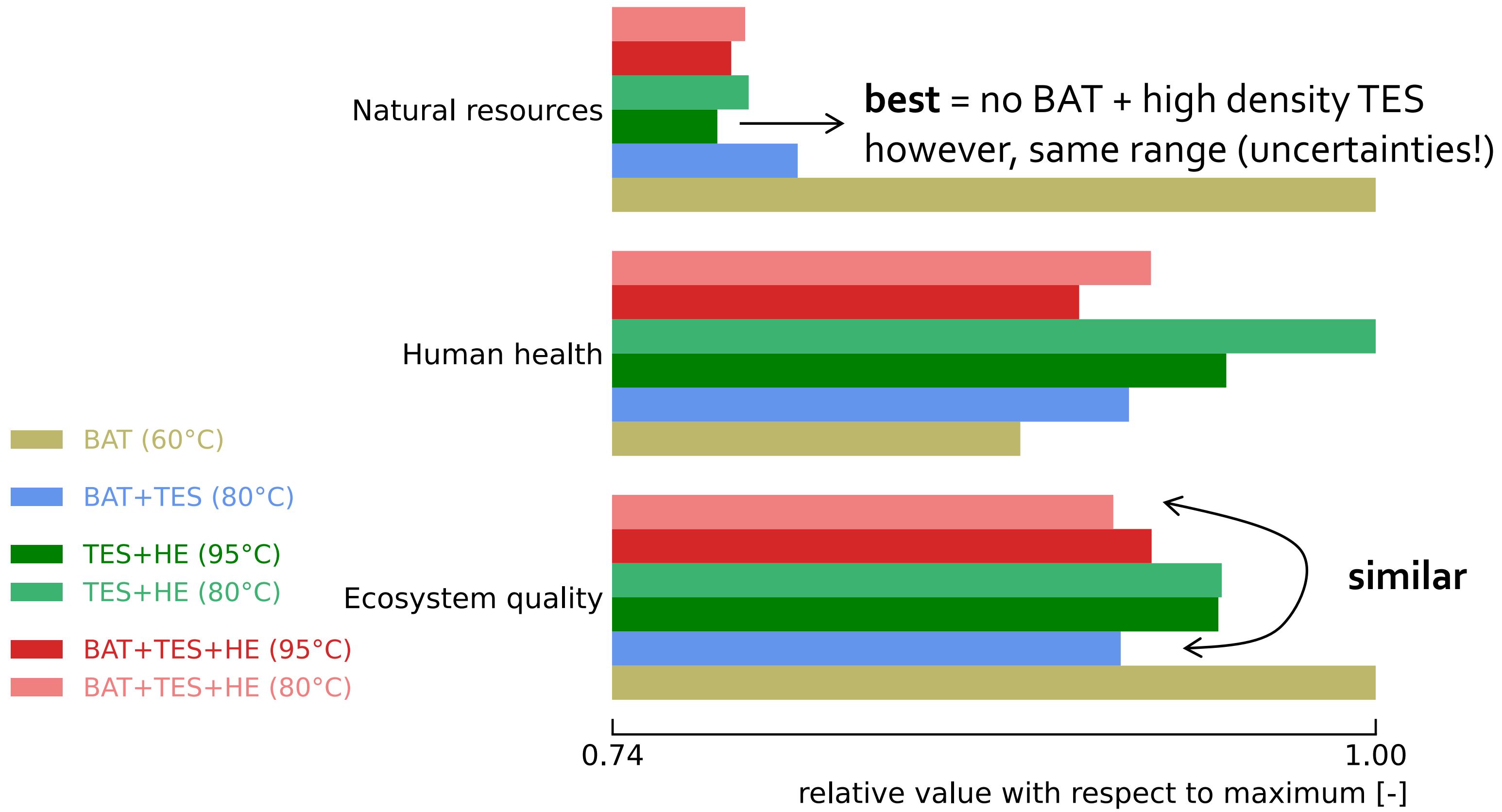


3 endpoints to get clearer message out of 18 midpoints

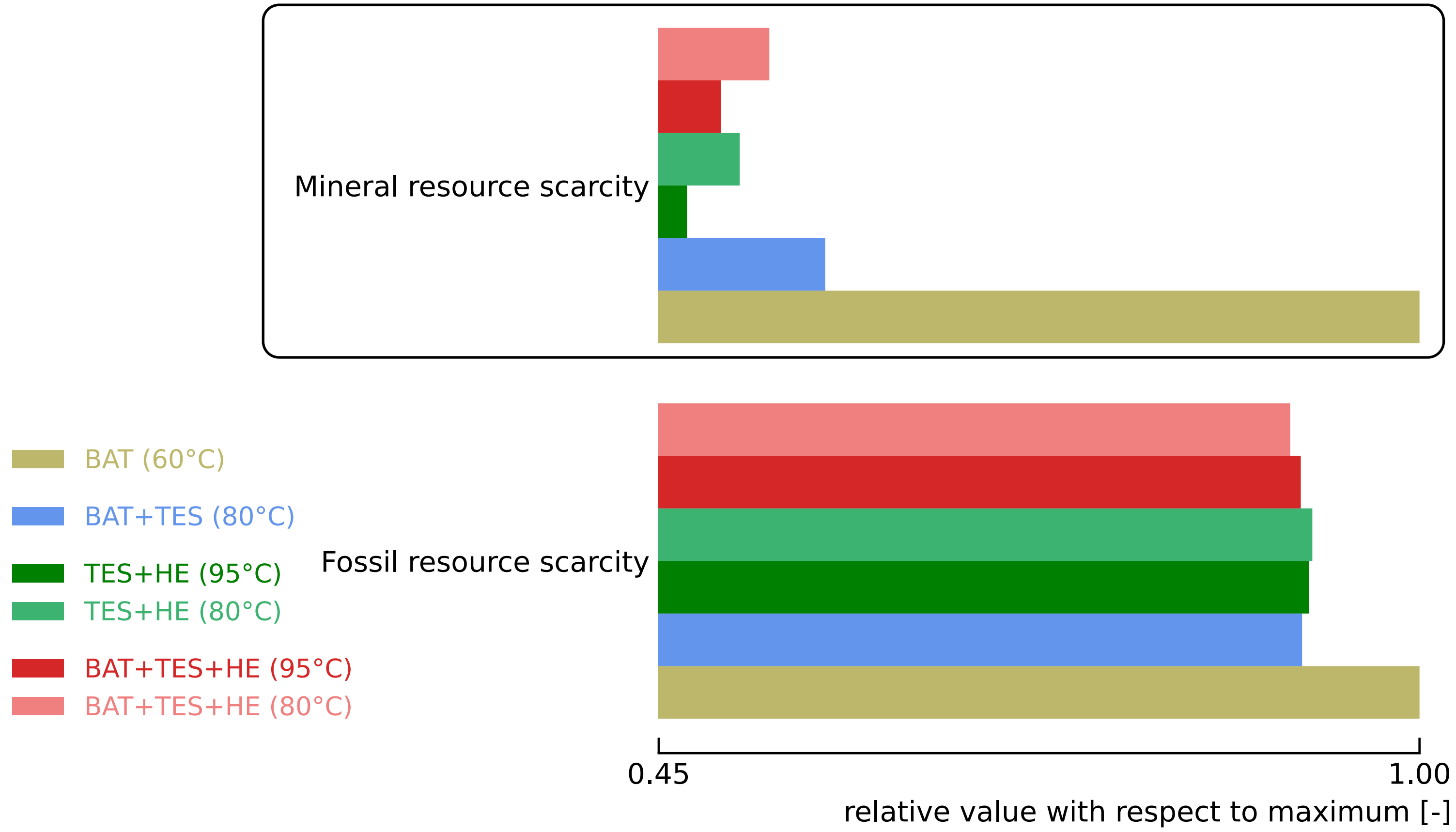


18 midpoints **3 endpoints**

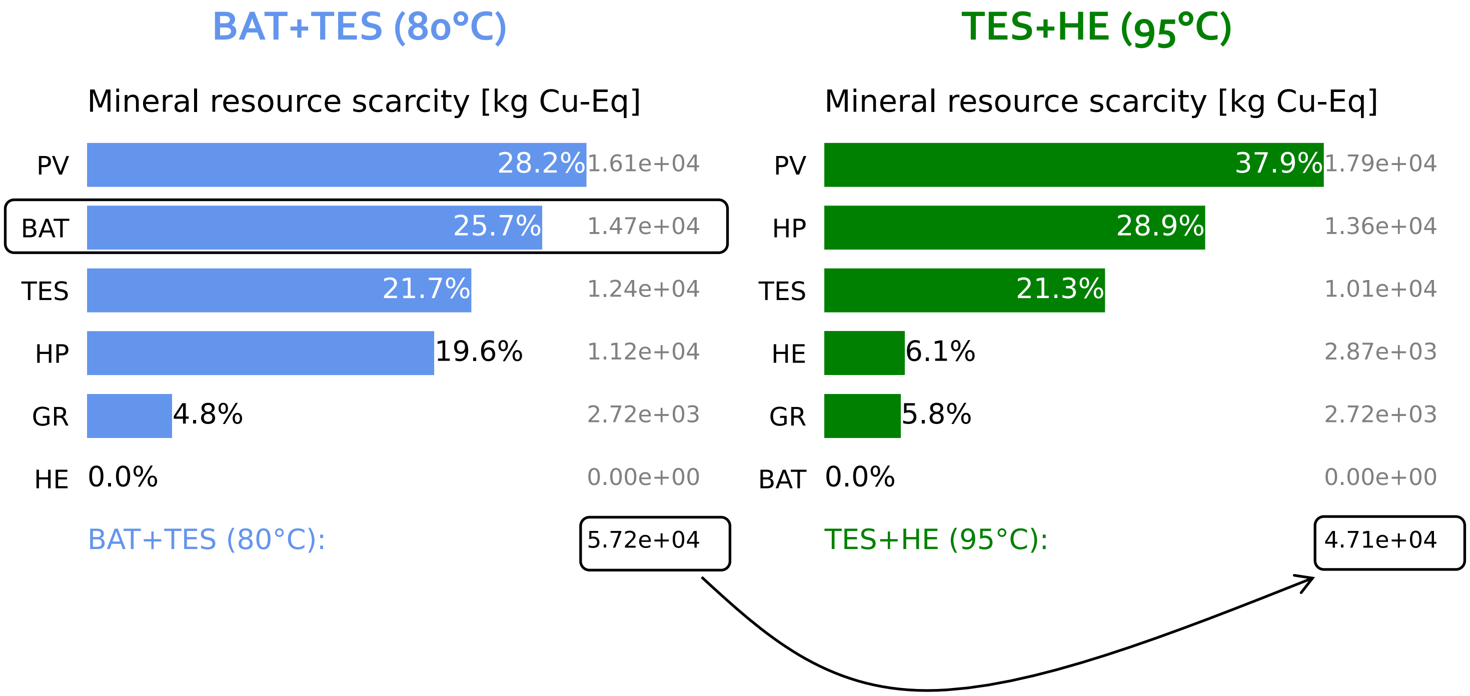
3 endpoints to aggregate and synthetise results



What are the main contributors to natural resources availability?

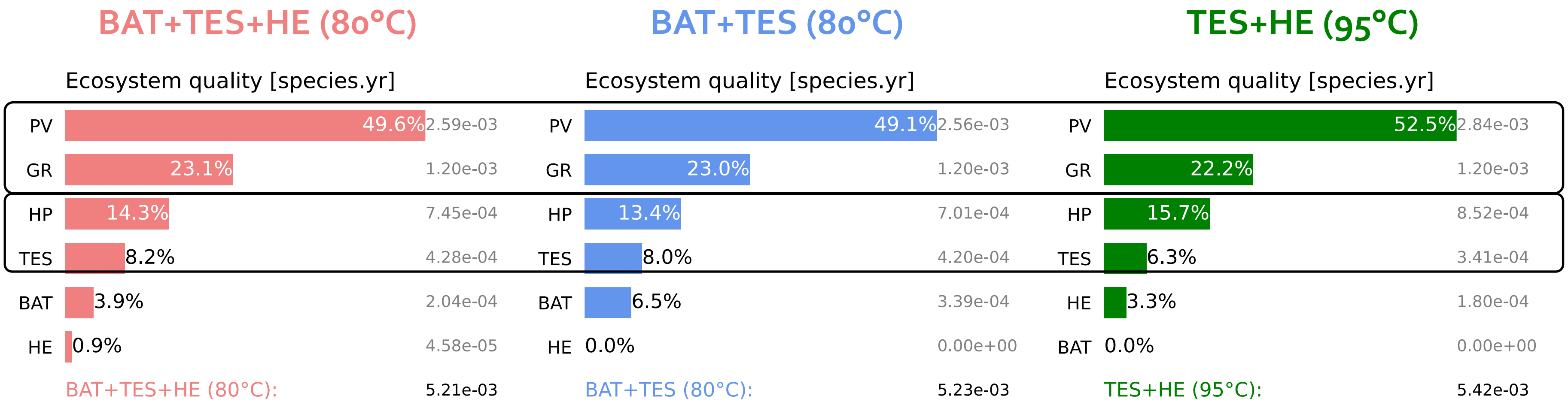


TES + HE reduces mineral scarcity by -18% compared to TES + BAT



Carnot battery reduces total impact by -18% (relatively)

PV + GR affect most ecosystem, HP + TES come next



What about Brussels? Lower PV potential, cleaner electricity mix, larger thermal demand

Mismatch between PV and heat demand is a severe drawback

Goal and Scope Definition

Life Cycle Inventory (LCI)

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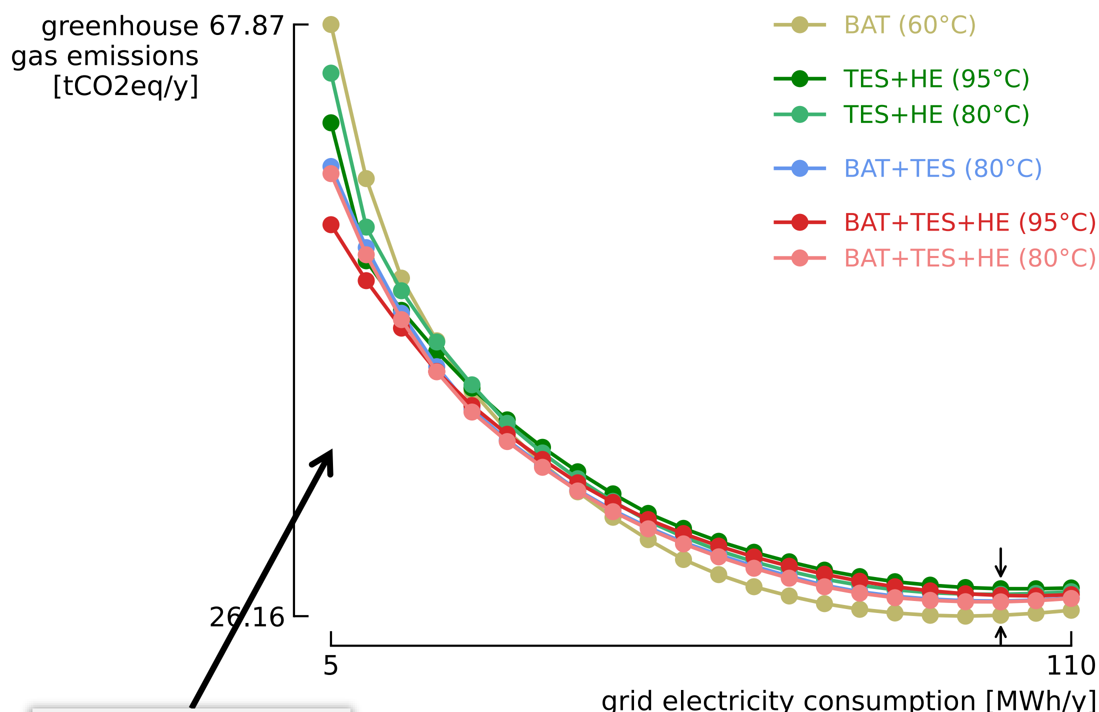
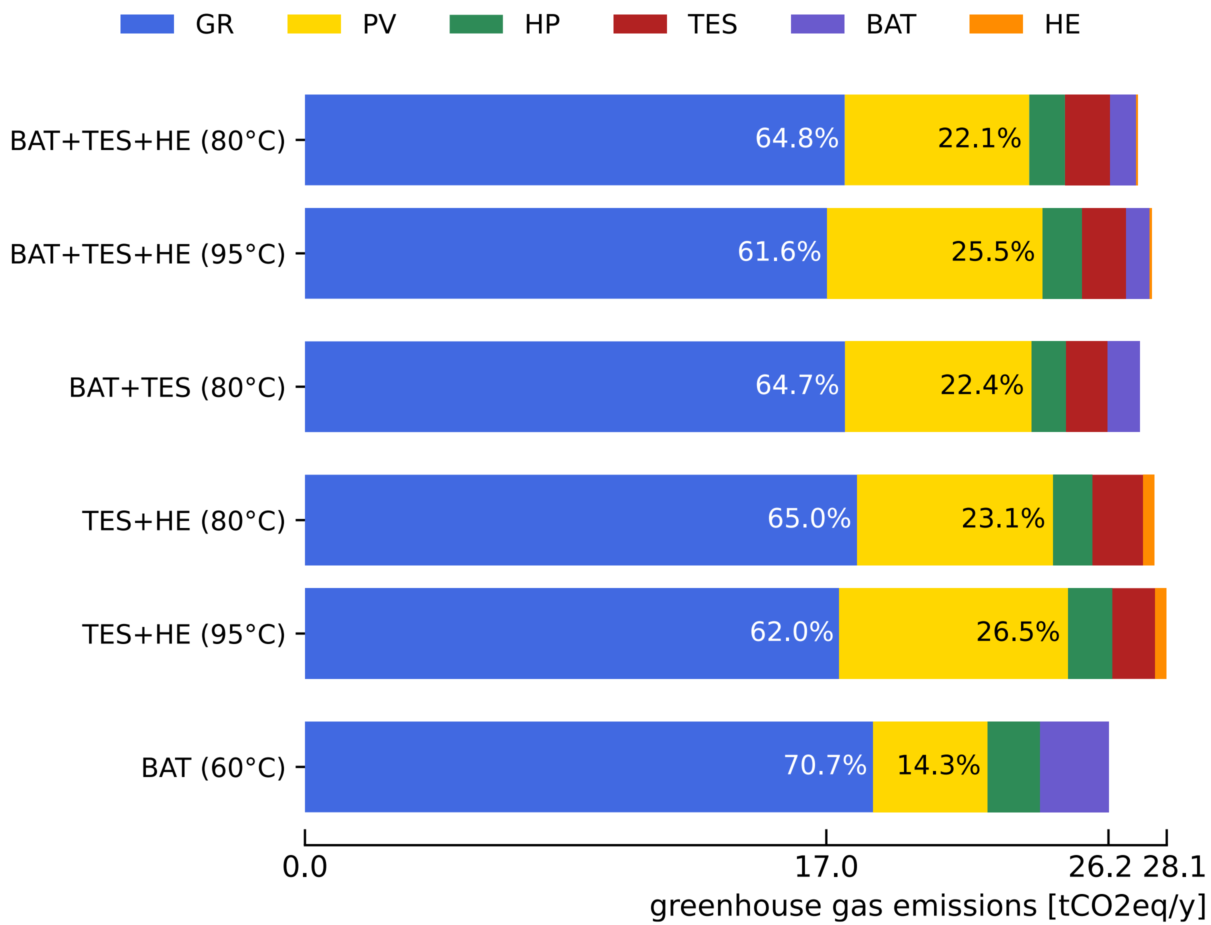
For fair comparison, each topology provides **same consumption of grid electricity** (i.e. self-sufficiency)

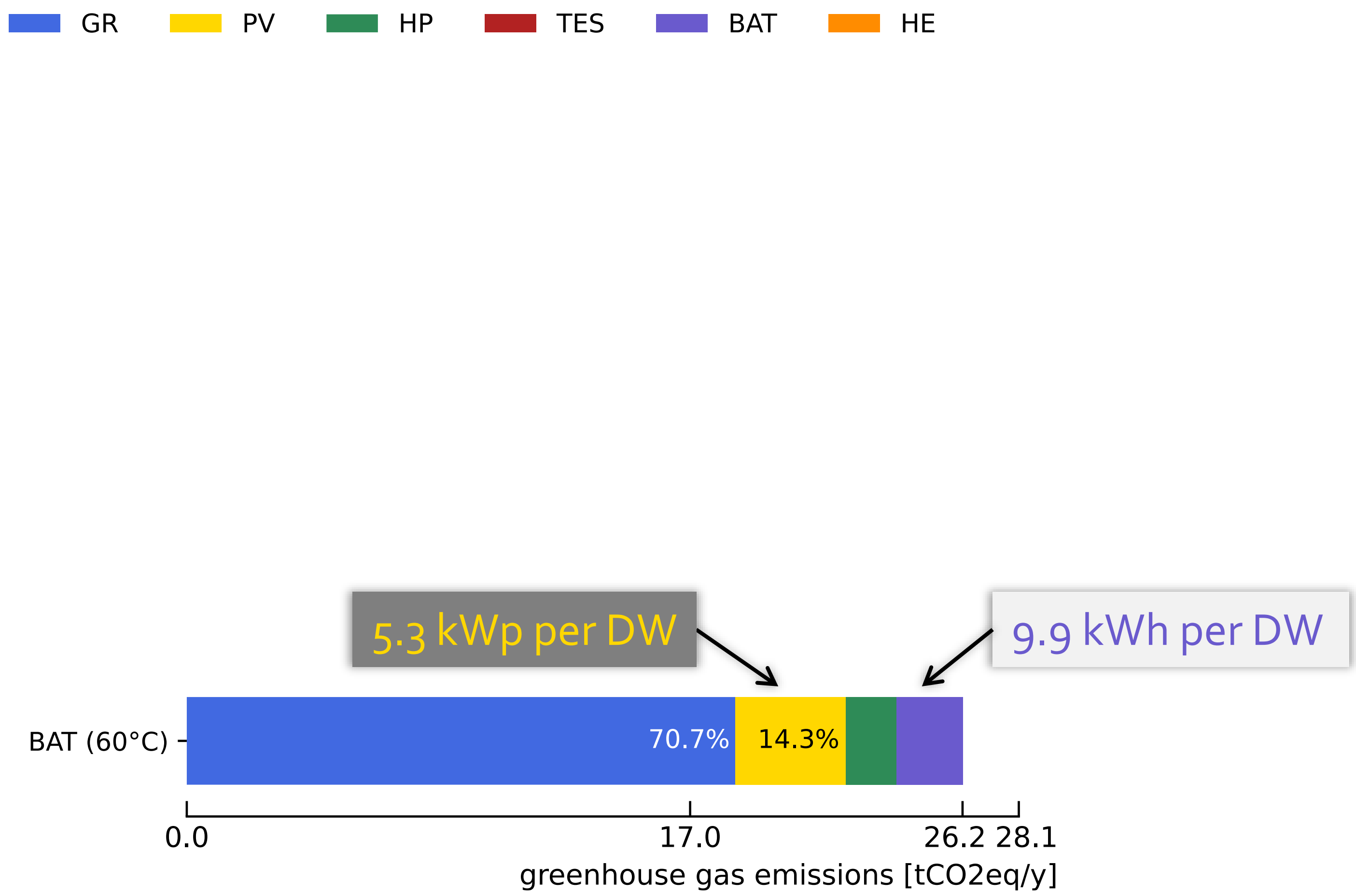


max. self-sufficiency:
wrong idea

Much less PV is installed so GR is the first source of GHG



Best design contains much less PV and no TES (BAT only)



Five main take aways

Best design contains CB + BAT. Yet, **CB not game changer** (very slight difference).

Most of the system **impact is driven by photovoltaic and grid**.

Carnot batteries help to **reduce the impact on mineral resources** (and other indicators).

Results depend on boundary conditions.

*Carnot battery would be more profitable where demand for **higher temperature heat**.*

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Thank you!

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