Designing Custom Carnot Batteries to Suit Your Exigencies: A Near-Optimal Approach

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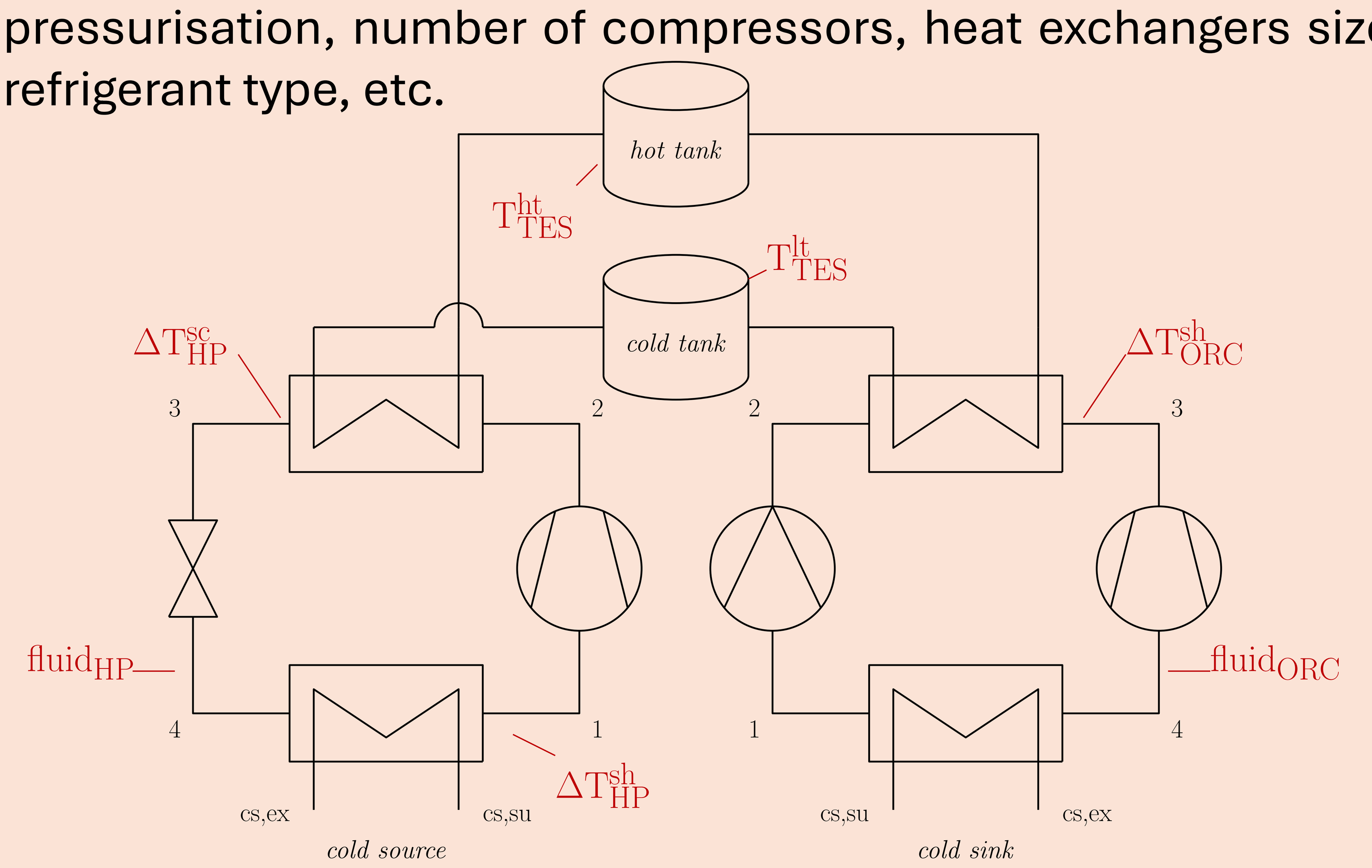
Objective

Conducting near-optimal analyses to generate multiple alternatives for the thermodynamic design of Carnot batteries, tailored to meet manufacturers technological preferences.

The Optimum is Not Enough

- **Different thermodynamic designs** of Carnot batteries can achieve **similar performance** (efficiency η_{CB}^{elec}, density ρ_{CB}^{elec}).
- Yet, they involve **technological trade-offs**, such as storage pressurisation, number of compressors, heat exchangers size, refrigerant type, etc.



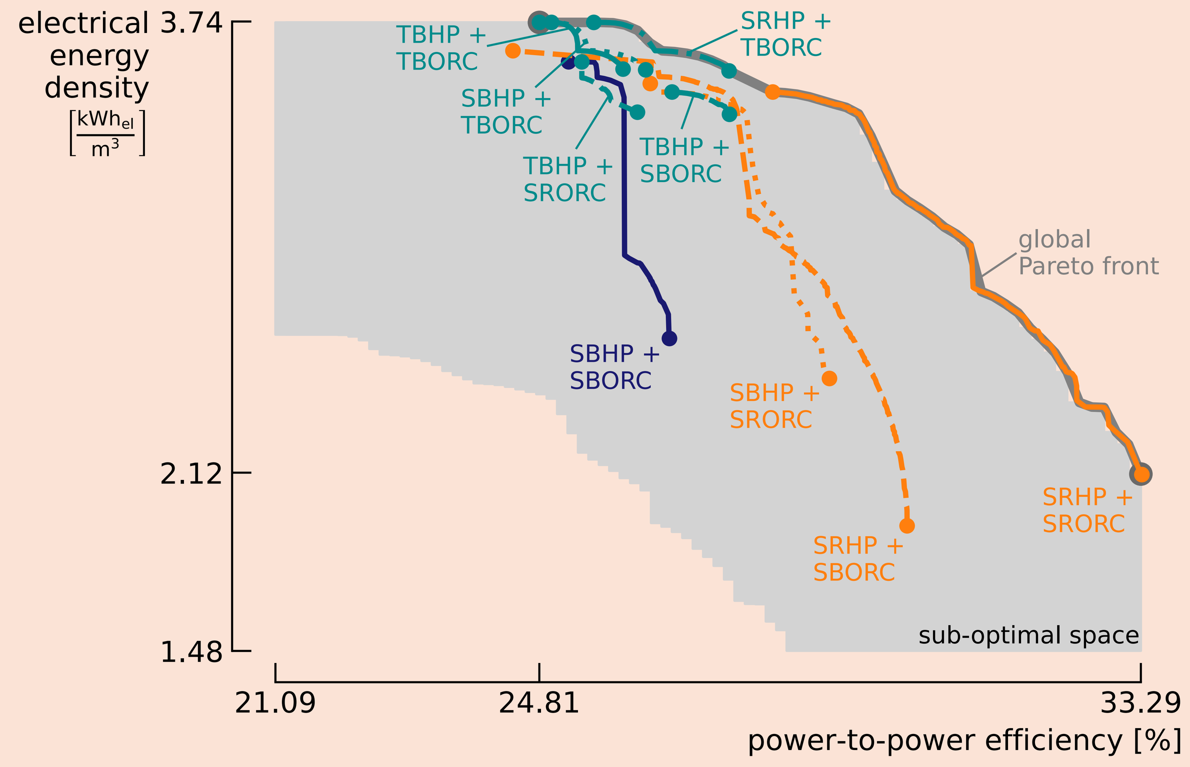
- These factors affect techno-economic outcomes and depend on **manufacturers strategic choices**, based on, e.g., supply chain, experience, service lifetime, maintenance needs, business model and risk tolerance.
- **Near-optimal exploration** can offer design alternatives to help manufacturers select the **best fit for their needs**.

Identifying the Sub-Optimal Space

- Nine Carnot battery types are optimised with **NSGA-II** to **maximise η_{CB}^{elec}** and **ρ_{CB}^{elec}**.

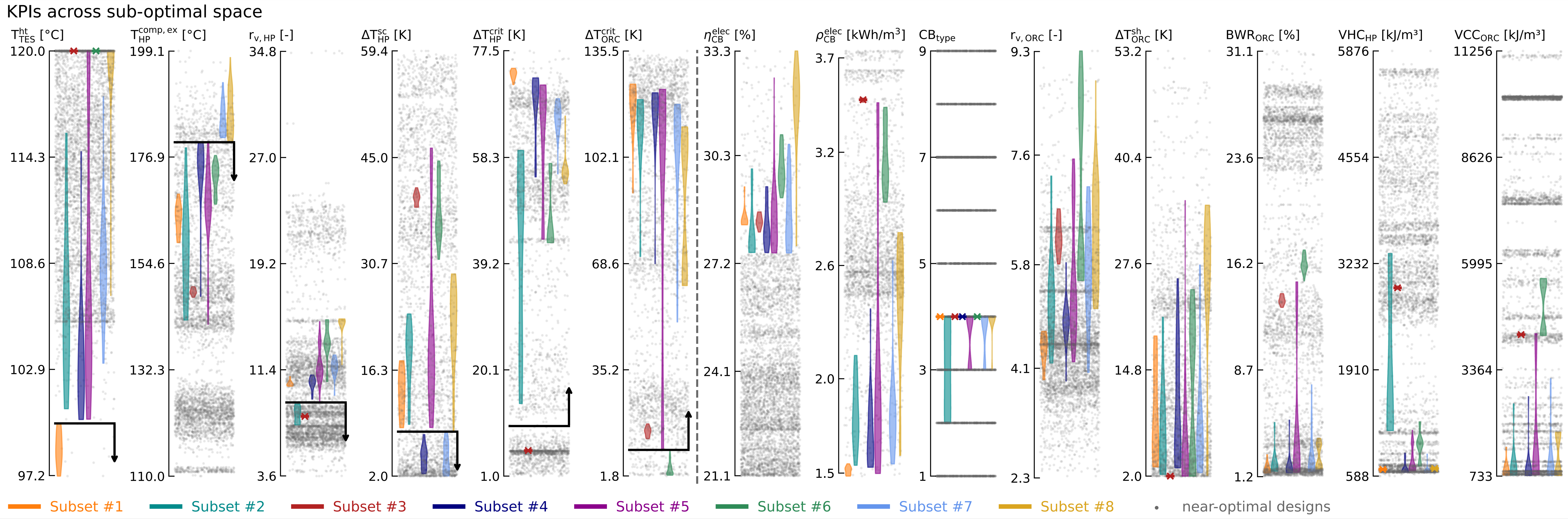
			Heat Pump		
			Subcritical		Transcritical
			Basic	Recuperated	Basic
Organic Rankine Cycle	Subcrit.	Basic	#1: SBHP + SBORC	#3: SRHP + SBORC	#6: TBHP + SBORC
		Recup.	#2: SBHP + SRORC	#4: SRHP + SRORC	#8: TBHP + SRORC
	Transcrit.	Basic	#5: SBHP + TBORC	#7: SRHP + TBORC	#9: TBHP + TBORC

- Resulting fronts are combined to create a **global Pareto front**.



- The **sub-optimal** space is then defined, allowing for near-optimal designs with maximum **sub-optimality coefficients** of **15% for η_{CB}^{elec}** and **30% for ρ_{CB}^{elec}**.

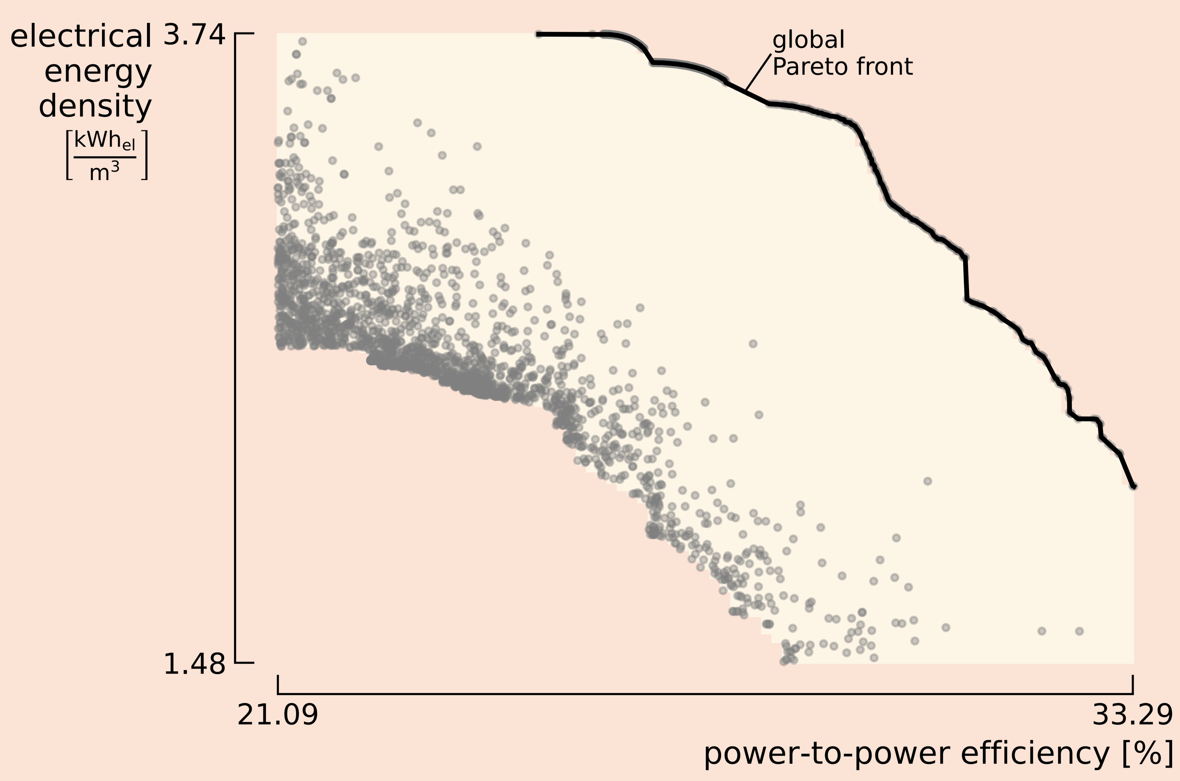
KPIs across sub-optimal space



	T_{TES}^{ht} [°C] < 100	$T_{HP}^{comp,ex}$ [°C] < 180	$r_{v,HP}$ [-] < 9	ΔT_{HP}^{sc} [K] < 8	ΔT_{HP}^{crit} [K] > 10	ΔT_{ORC}^{crit} [K] > 10
Subset #1	✔	✔	✗	✗	✔	✔
Subset #2	✗	✔	✔	✗	✔	✔
Subset #3	✗	✔	✔	✗	✗	✔
Subset #4	✗	✔	✗	✔	✔	✔
Subset #5	✗	✔	✗	✗	✔	✔
Subset #6	✗	✔	✗	✗	✔	✗
Subset #7	✗	✗	✗	✔	✔	✔
Subset #8	✗	✗	✗	✗	✔	✔

Generating the Near-Optimal Designs

- The **near-optimal designs** are then generated for each type of Carnot battery, also using NSGA-II.
- These **maximise the Euclidean distance (i.e., the difference) from the nearest design** of the corresponding Pareto front.



Choosing the Design that Suits Your Needs

- Manufacturers **select designs** based on **their own criteria**.
- In this case, designs are chosen with $\eta_{CB}^{elec} > 27.5\%$ and meeting the following conditions:
  1. No pressurization required for storage $T_{TES}^{ht} < 100$°C (cost reduction).
  2. Compressor discharge temperature $T_{HP}^{comp,ex} < 180$°C (lubrication).
  3. Compression volume ratio $r_{v,HP} < 9$ (limits machines in series).
  4. Sub-cooling in heat pump $\Delta T_{HP}^{sc} < 8$ K (charge and condenser design).
  5. Saturation temperatures far from critical point $\Delta T_{HP,ORC}^{crit} > 10$ K (avoids near-critical regimes).
- No design meets all criteria simultaneously: different **subsets are highlighted**, along with their **associated design choices** (the so called *'real choices'*) and **fixed requirements** (the so called '*must-haves*').

Conclusion

Method to generate diverse Carnot battery designs beyond the single thermodynamic optimum, allowing for the inclusion of other performance indicators based on manufacturers needs.

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