Design Optimisation and Global Sensitivity Analysis of a Carnot Battery Towards Integration in a Data Centre under Techno-Economic Uncertainties

Presentation at 5th SEE SDEWES conference

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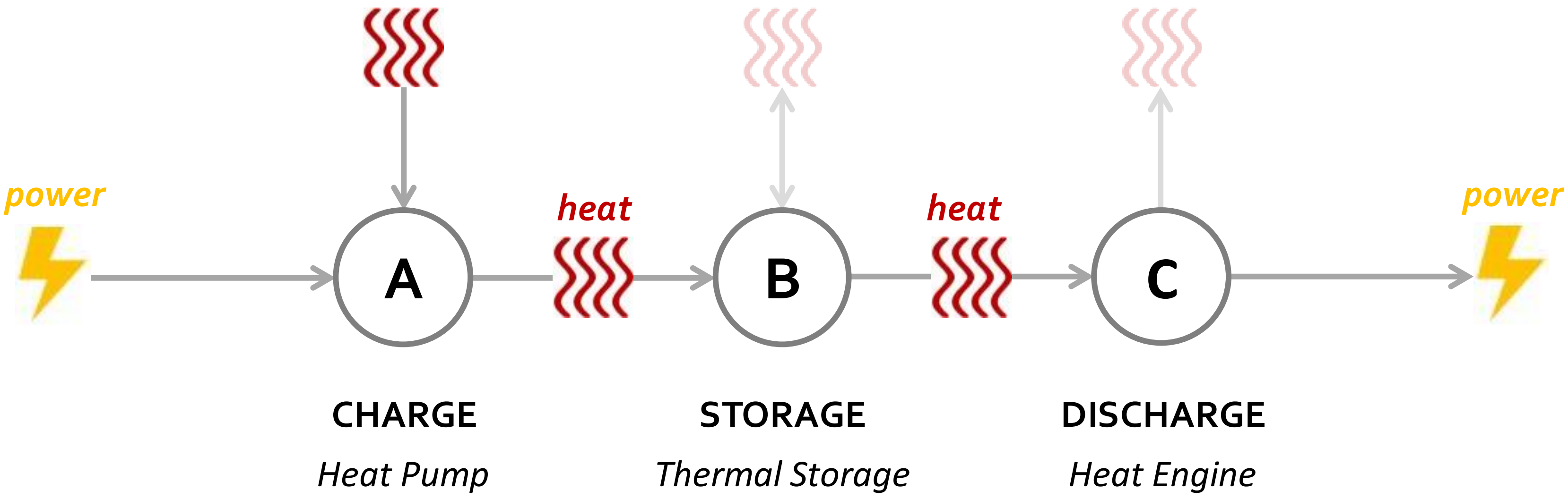
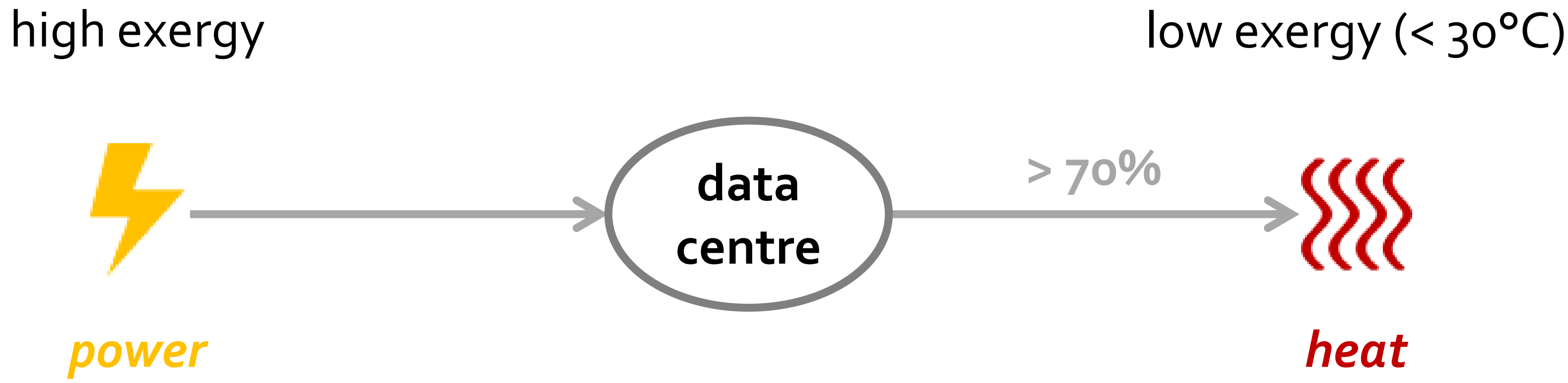
LaboThAp

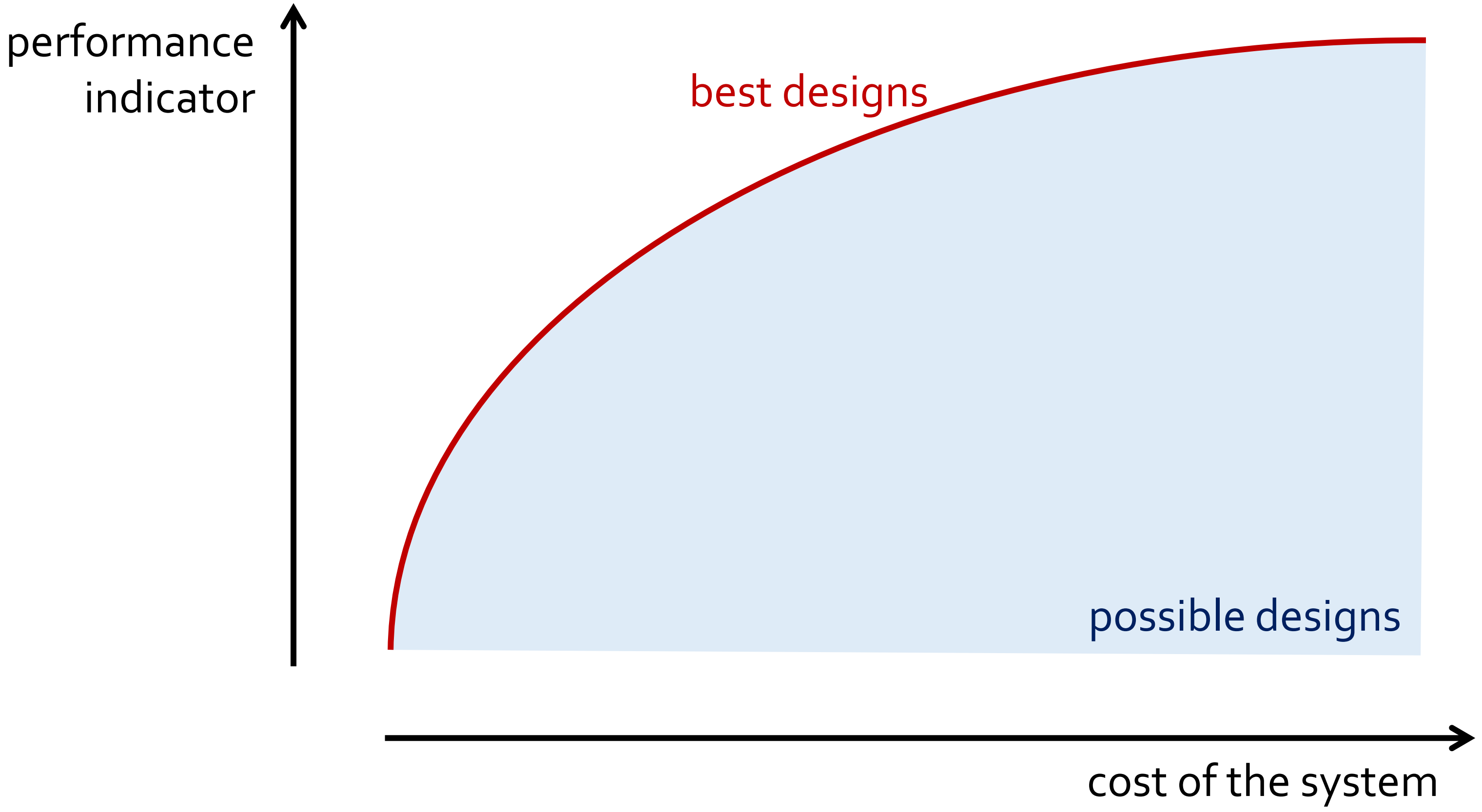
Carnot batteries are a flexibility option for energy systems



Data centres produce very low grade heat



How could Carnot batteries be integrated into data centres?



Outline

1. System and model description
2. Optimisation problem
3. Uncertainty quantification
4. Results
5. Conclusion and perspectives

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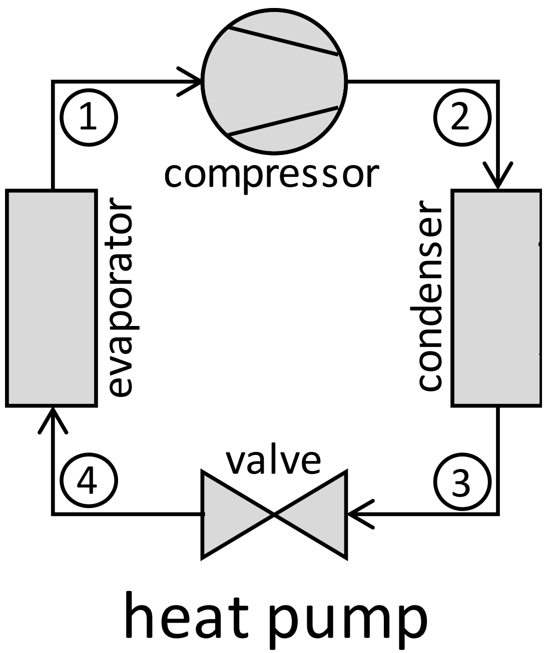
This Carnot battery is based on the Rankine cycle



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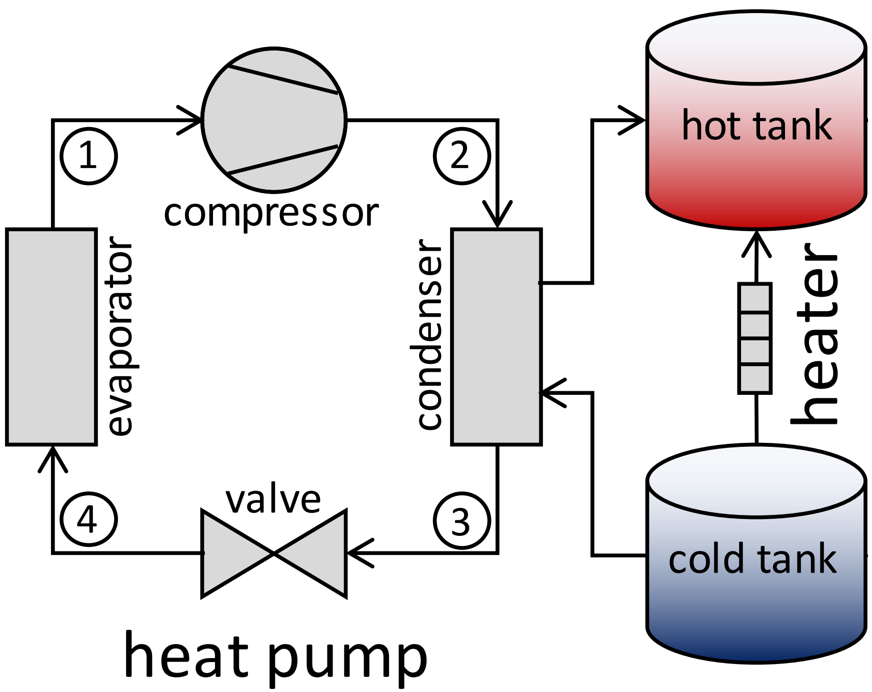

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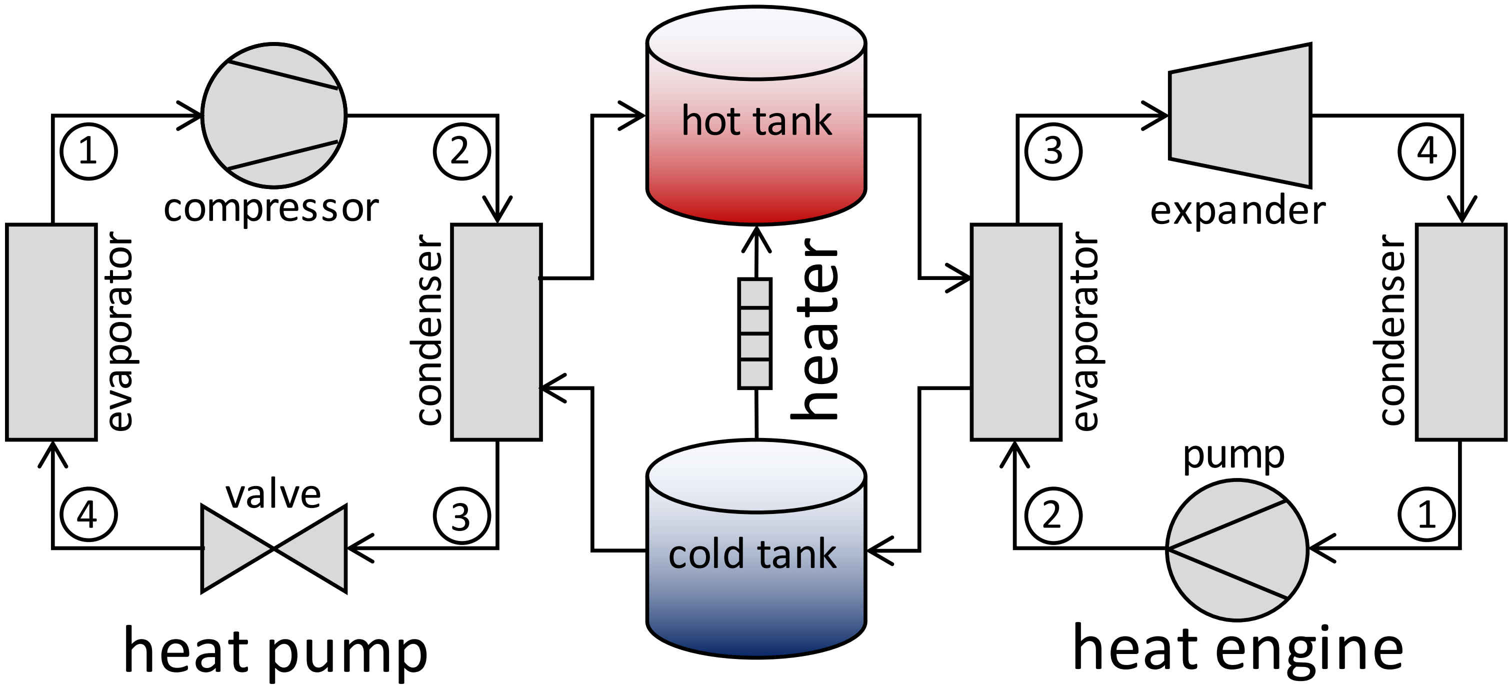

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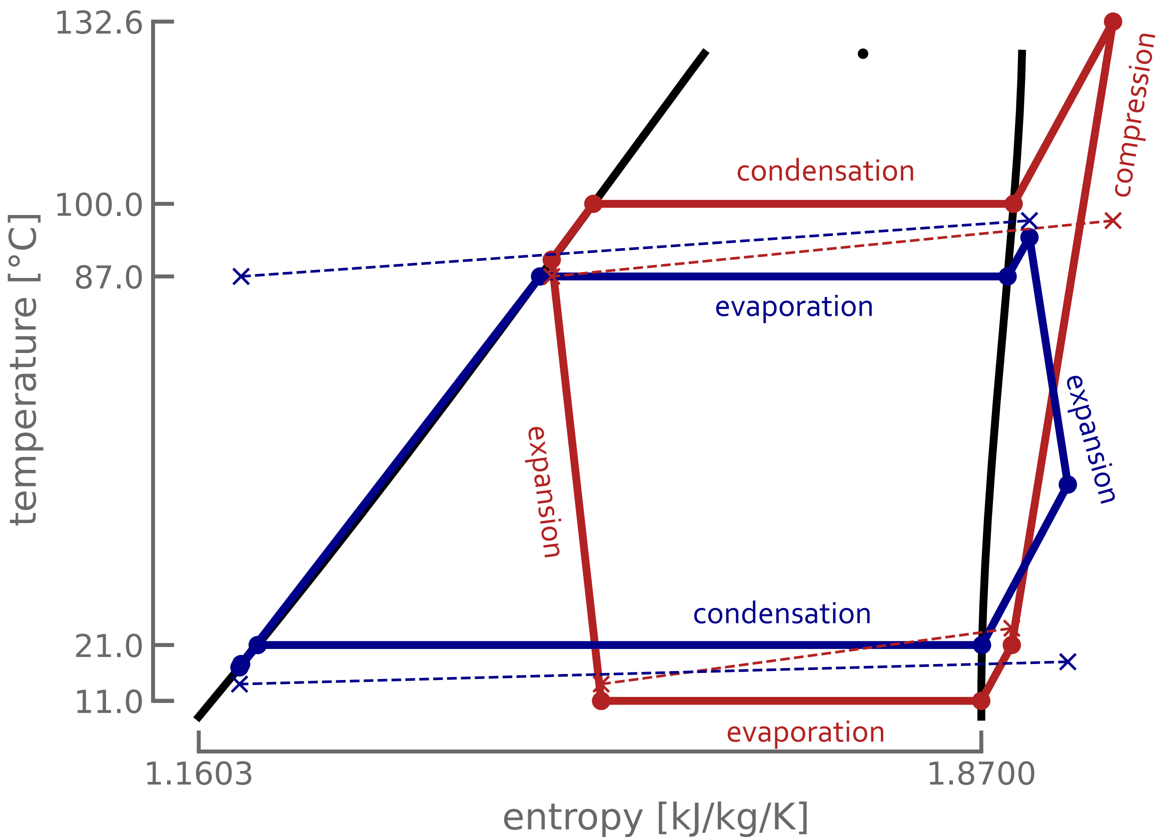
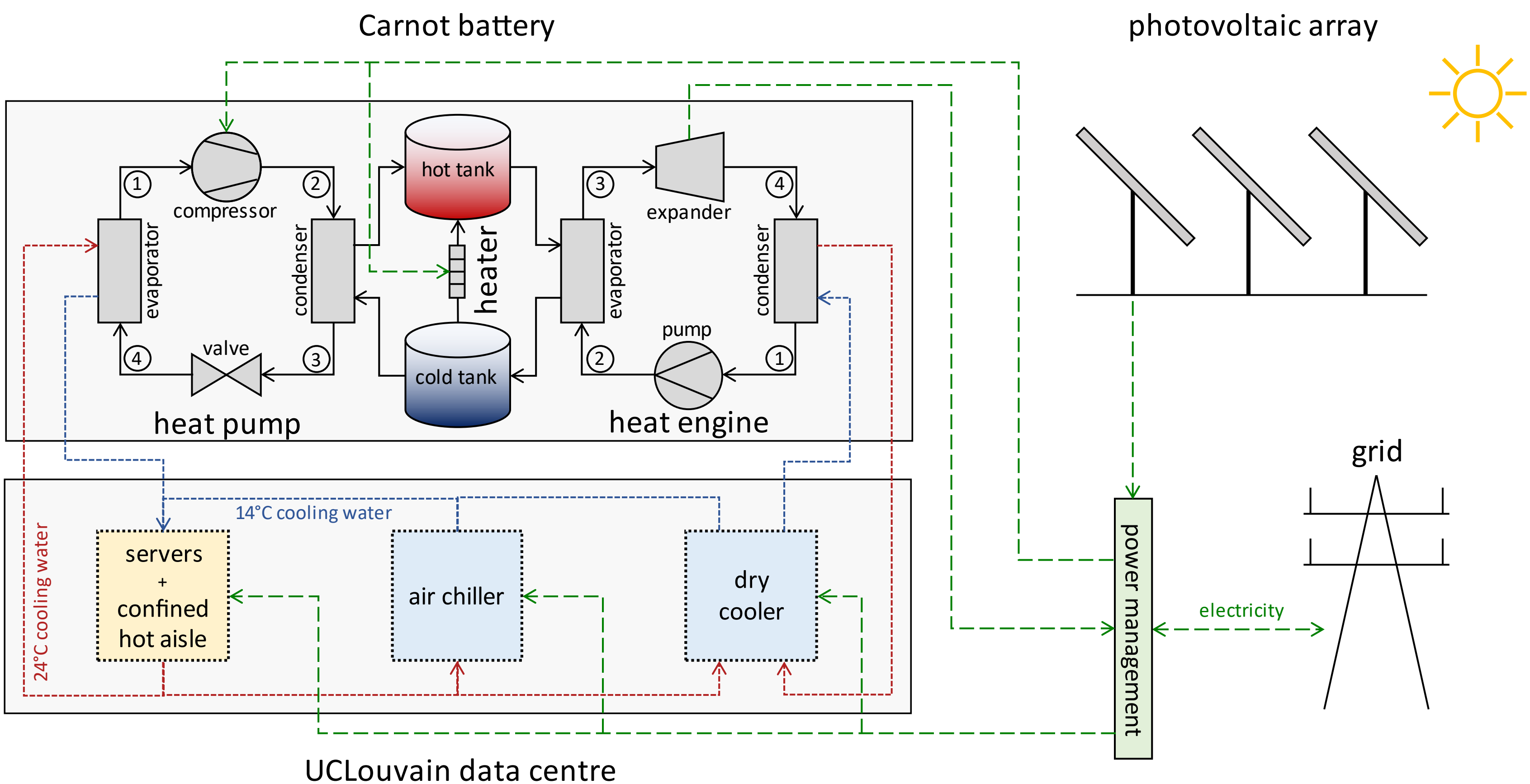
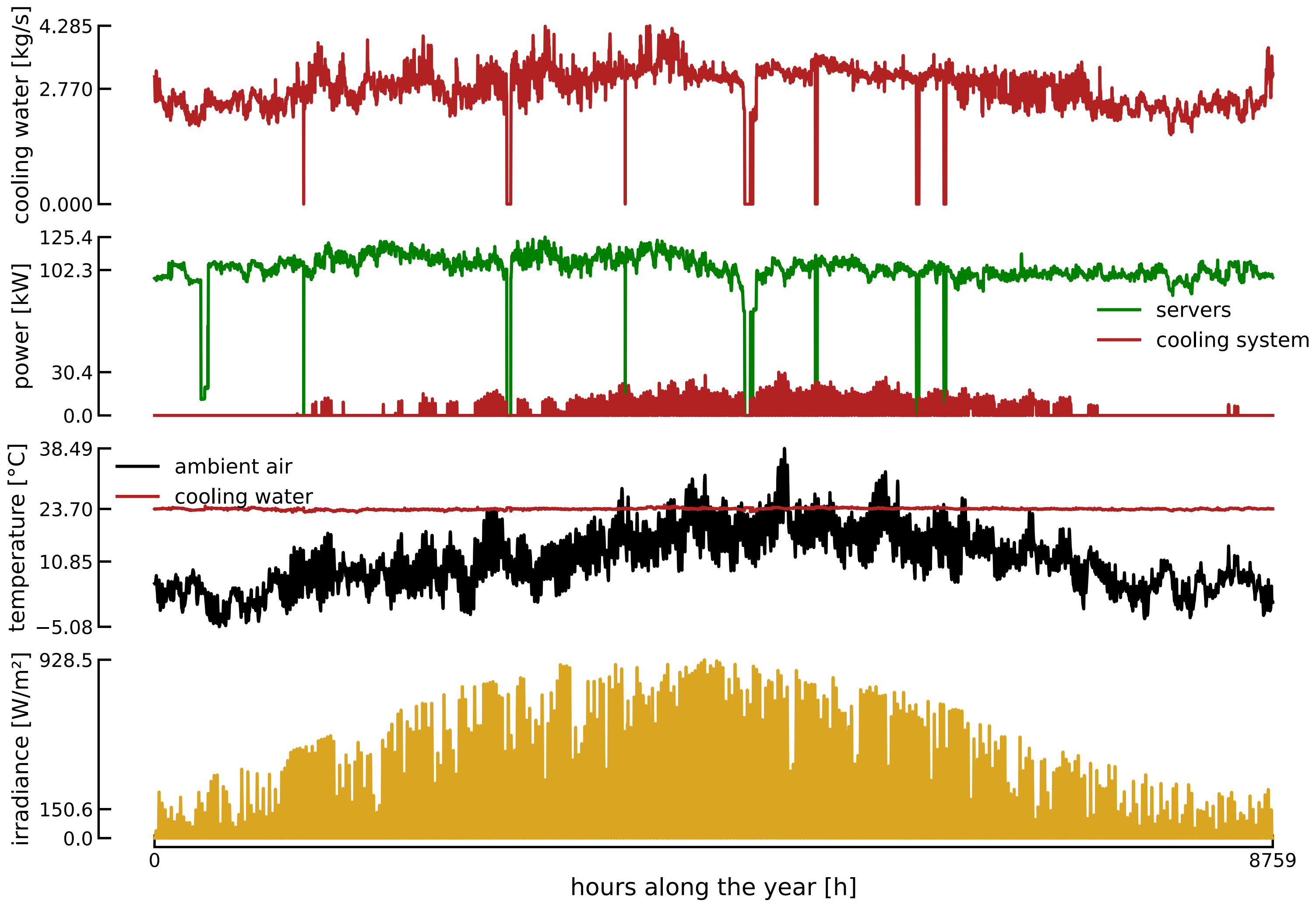


A possible thermal integration in the UCLouvain data centre



Real time series are used to run annual simulations



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The goal is to maximise the SSR and to minimise the LCOE

Economic: Levelized Cost Of Electricity (**LCOE**)

$$\mathbf{LCOE} = \frac{\text{cost of the system}}{\text{energy consumed}}$$

Technical: Self-Sufficiency Ratio (**SSR**)

$$\mathbf{SSR} = 1 - \frac{\text{energy from the grid}}{\text{energy consumed}}$$

This optimisation problem has 9 design variables

1.	Compressor volume ratio	1.5	5	[-]
2.	Compressor swept volume	0	1e+4	[cm³]
3.	Expander volume ratio	1.5	5	[-]
4.	Expander swept volume	0	1e+4	[cm³]
5.	HP condensing temperature	25	100	[°C]
6.	HP sub-cooling	0	70	[°C]
7.	Tanks volume	0	1e+3	[m³]
8.	PV array peak power	0	800	[kW]
9.	RH maximum power	0	800	[kW]

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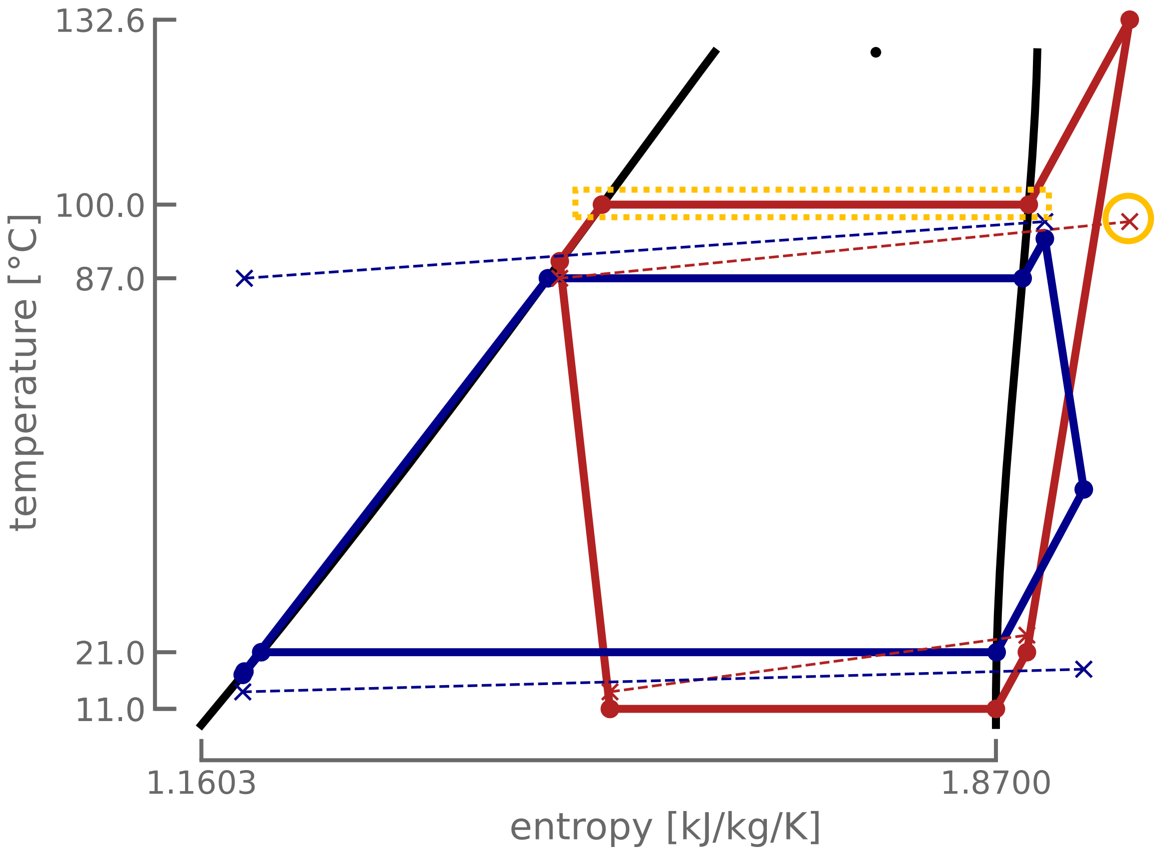
Condensing temperature in HP sets the storage temperature



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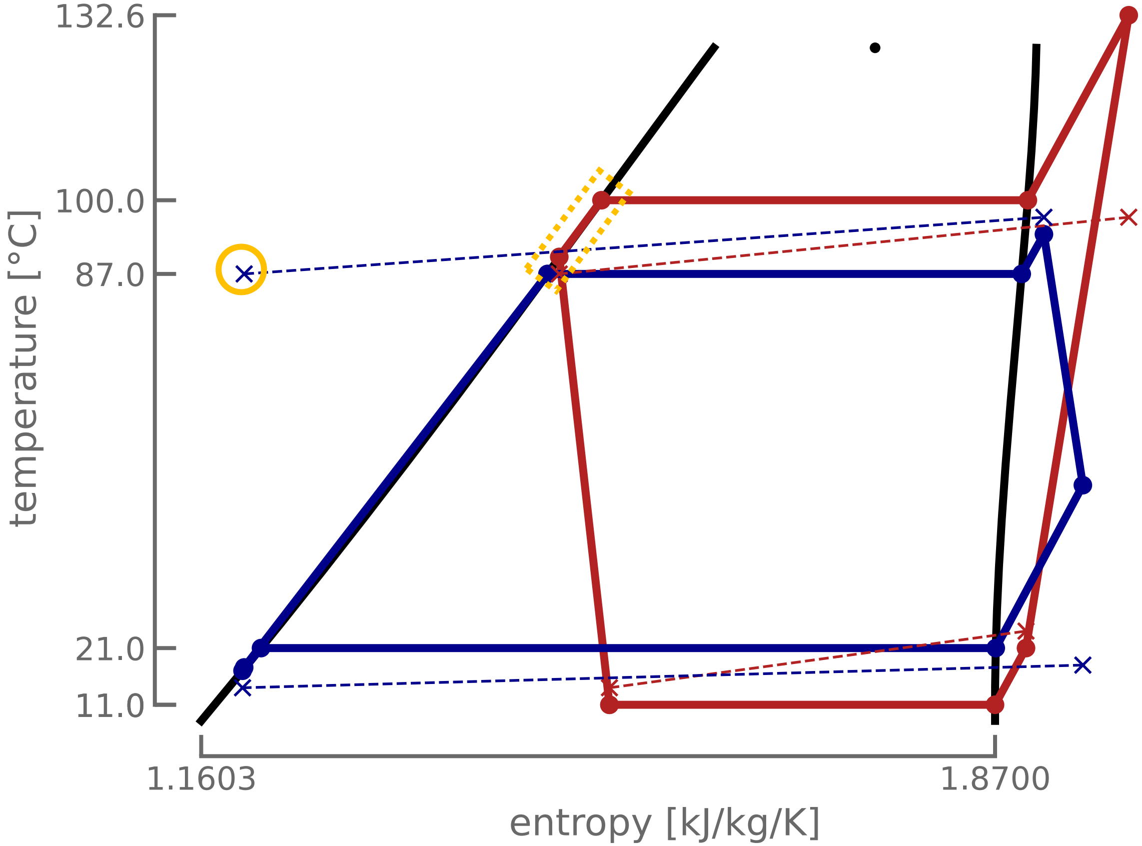
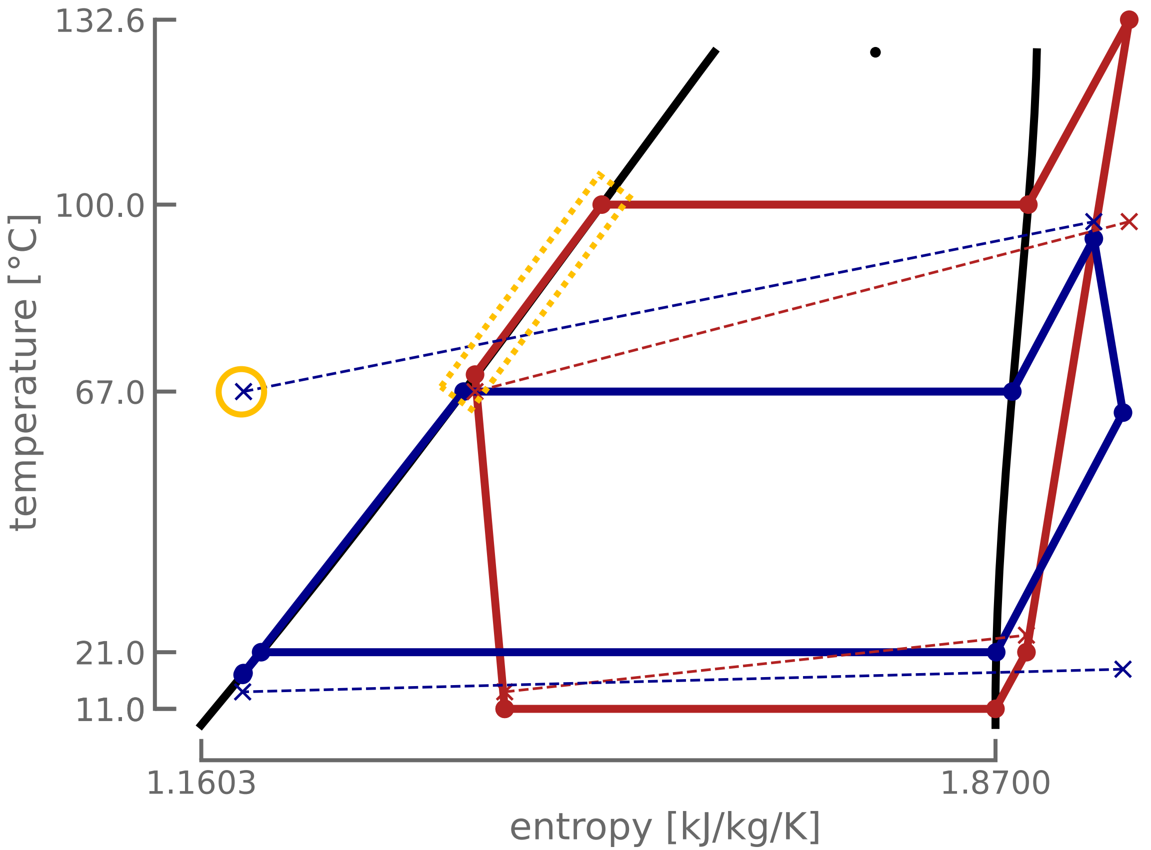
7.	Tanks volume	0	1e+3	[m^3]
8.	PV array peak power	0	800	[kW]
9.	RH maximum power	0	800	[kW]

Sub-cooling temperature in HP sets the LT storage temperature



Sub-cooling temperature in HP sets the LT storage temperature



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Modelling the costs: a very uncertain process…

Economic: Levelized Cost Of Electricity (**LCOE**)

$$\mathbf{LCOE} = \frac{\text{CAPEX} + \sum_{t=1}^{\text{LT}} \left(\frac{\text{OPEX}_t + c_{\text{el}} E_{\text{grid}}}{(1+r)^t} \right)}{\sum_{t=1}^{\text{LT}} \left(\frac{E_{\text{servers}}}{(1+r)^t} \right)}$$

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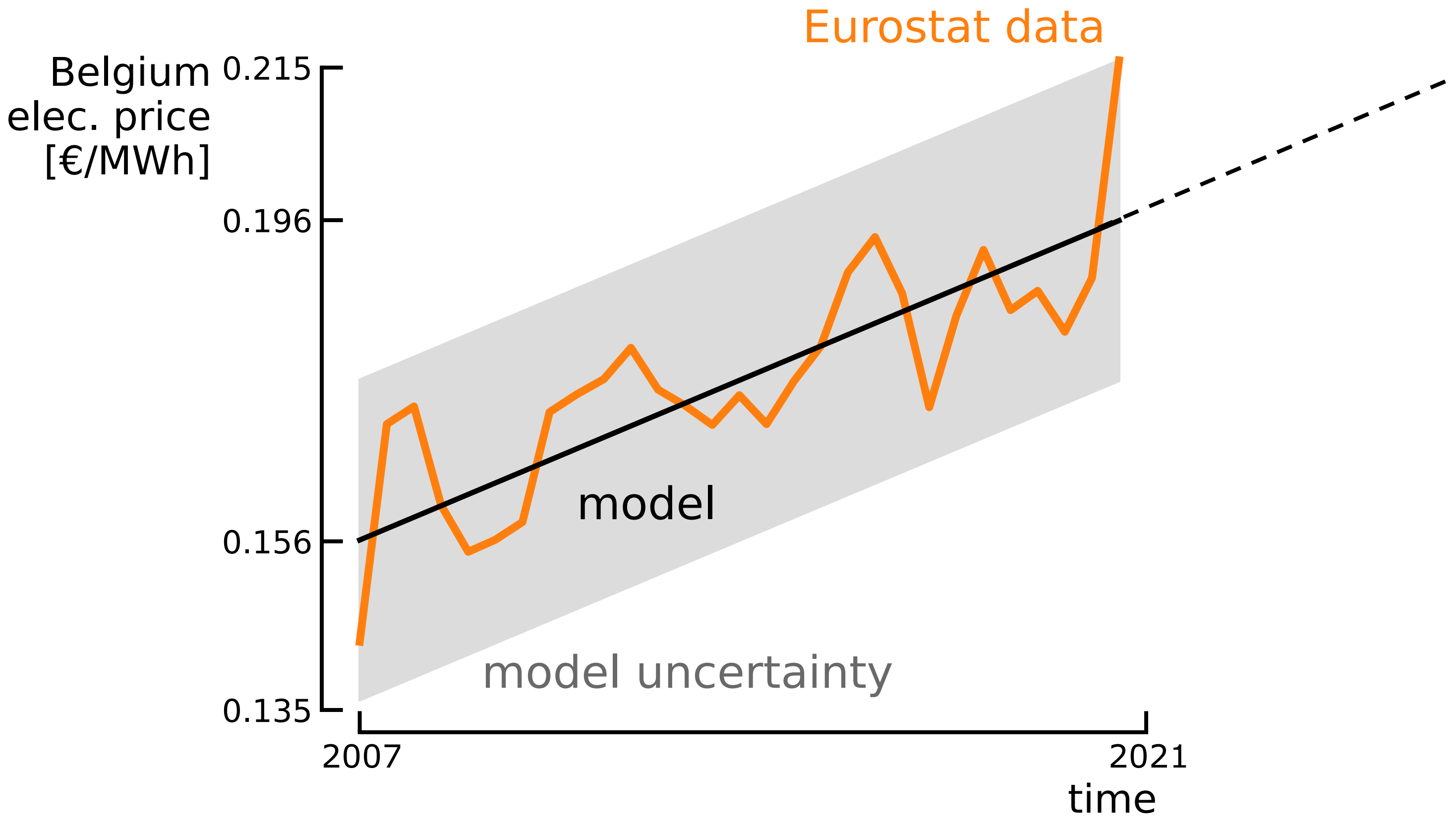
Electricity price is extrapolated from Band IB index (Eurostat)



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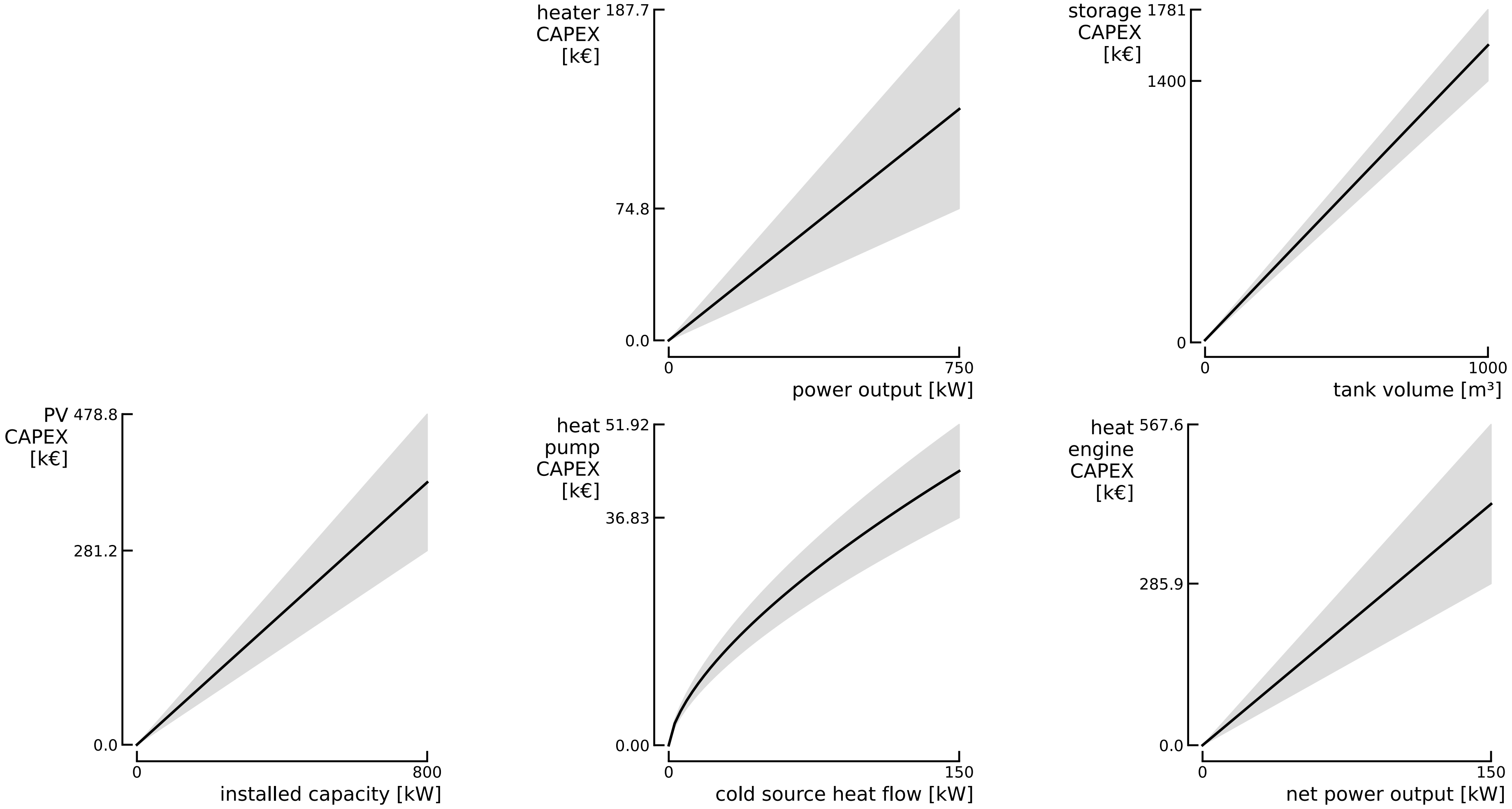
In this model, the CAPEX has five contributors



Polynomial Chaos Expansion is used to propagate the uncertainty

Uncertainty on 20 techno-economic parameters (see paper for more details)

Parameter	Units	Mean	Standard deviation	Distribution	Ref.
$\eta_{\mathrm{mech,comp}}$	[%]	72.5	2.5	uniform	[17], [33]
$\eta_{\mathrm{mech,exp}}$	[%]	72.5	2.5	uniform	[17], [33]
η_{pump}	[%]	55	10	uniform	[17]
$\Delta T_{\mathrm{pinch}}$	[°C]	3.0	1.0	uniform	[7], [17]
$\Delta p_{\mathrm{hp,ev}}$	$[mbar]$	50	50	uniform	[17]
$\Delta p_{\mathrm{hp,cd}}$	$[mbar]$	50	50	uniform	[17]
$\Delta p_{\mathrm{he,ev}}$	$[mbar]$	50	50	uniform	[17]
$\Delta p_{\mathrm{he,cd}}$	$[mbar]$	50	50	uniform	[17]
P_{servers}	$[W]$	annual data	5%	Gaussian	n.a.
$\dot{m}_{\mathrm{cooling}}$	$[kg/s]$	annual data			
$\eta_{\mathrm{chiller}}^{\mathrm{Carnot}}$	[%]	45	5	uniform	[34]
G	[%]	annual data	7.8	Gaussian	[35]
T_{ambient}	[°C]	annual data	0.4	Gaussian	[35]
$\mathrm{CAPEX_{HP}}$	[€]	correlation	$17\%_{\mathrm{CAPEX}}$	uniform	[26]
$\mathrm{CAPEX_{HE}}$	$[€/kW]$	2845	$35\%_{\mathrm{CAPEX}}$	uniform	[36]
$\mathrm{CAPEX_{ST}}$	[€]	correlation	$12\%_{\mathrm{CAPEX}}$	uniform	[29]
$\mathrm{CAPEX_{PV}}$	$[€/kW_p]$	475	125	uniform	[35]
$\mathrm{CAPEX_{RH}}$	$[€/kW]$	175	75	uniform	[18], [37]
$\mathrm{OPEX_{tot}}$	$[\%_{\mathrm{CAPEX_{tot}}}]$	2.0	1.0	uniform	[7], [11], [19]
$\varepsilon_{\mathrm{el}}$	[%]	0	9.2	uniform	[30]

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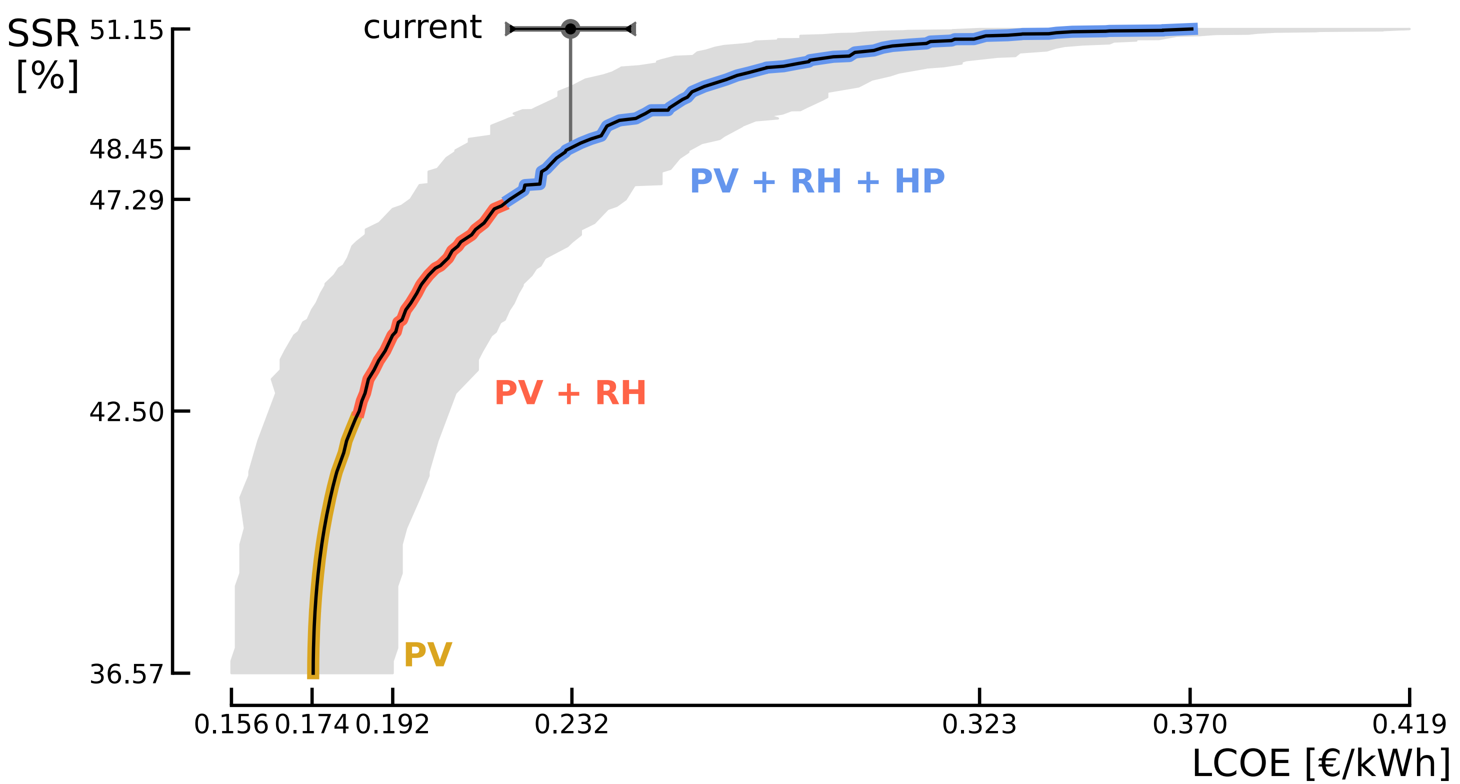
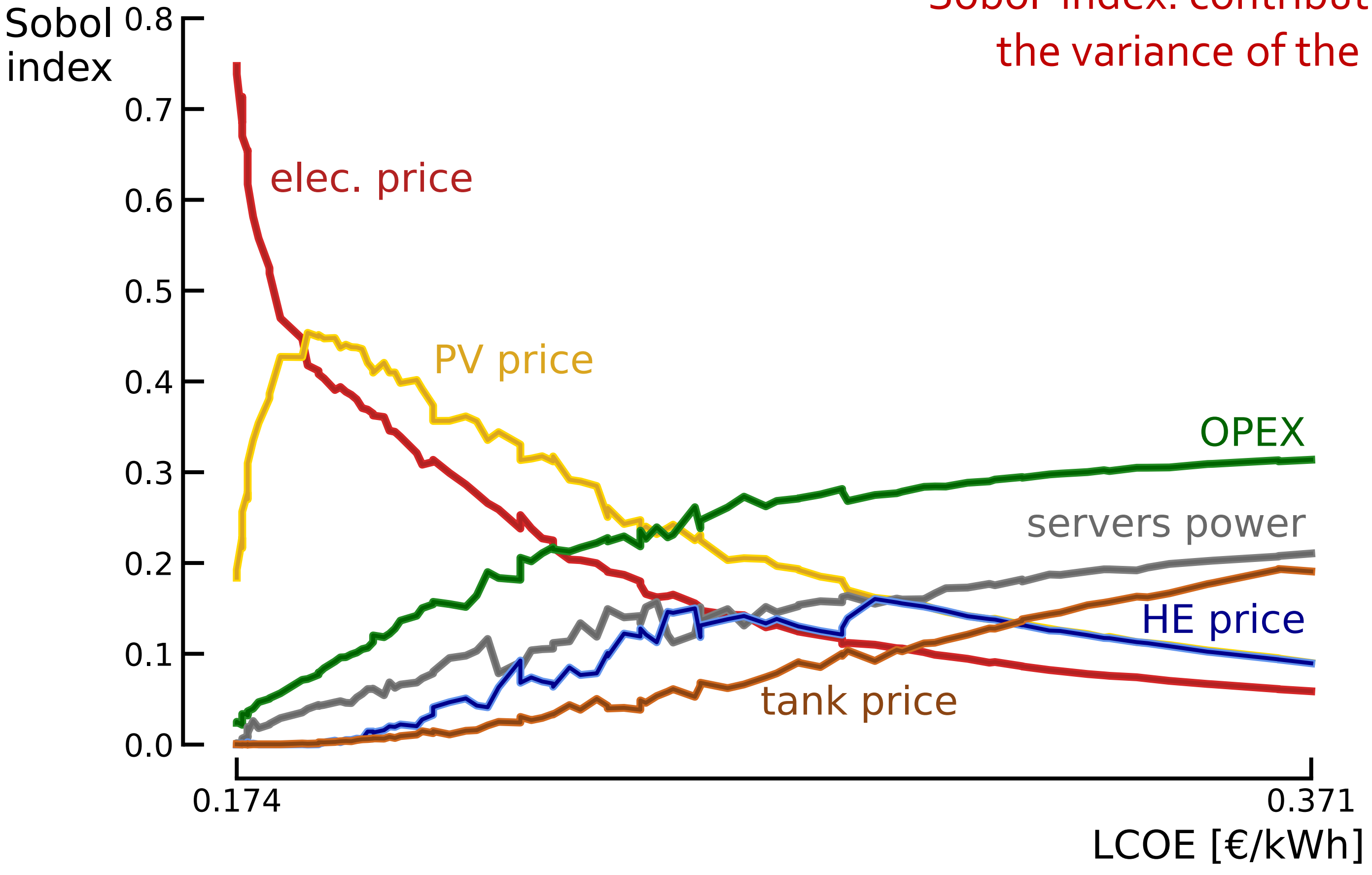
The LCOE exponentially increases with the SSR

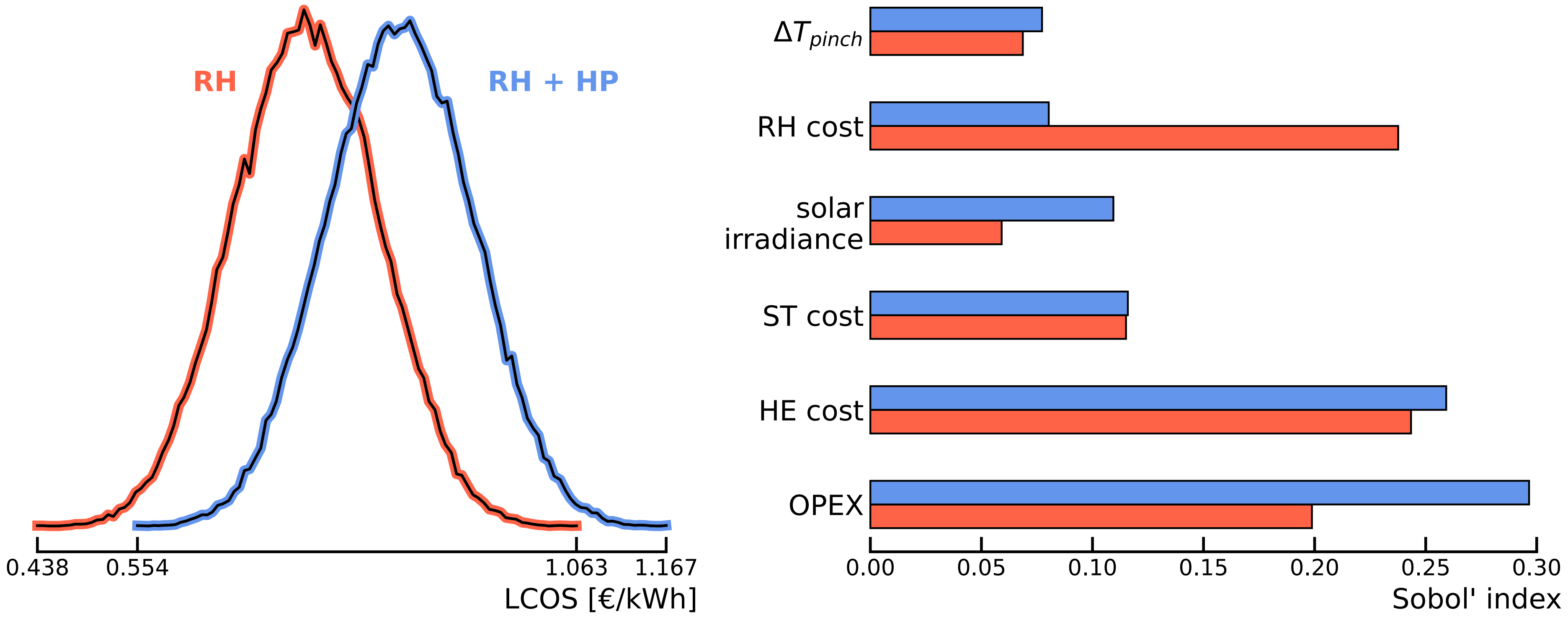
detailed explanation about the obtained designs in the paper!



Sobol indices show the dominant parameters



LCOS mean is big, and variance is very wide



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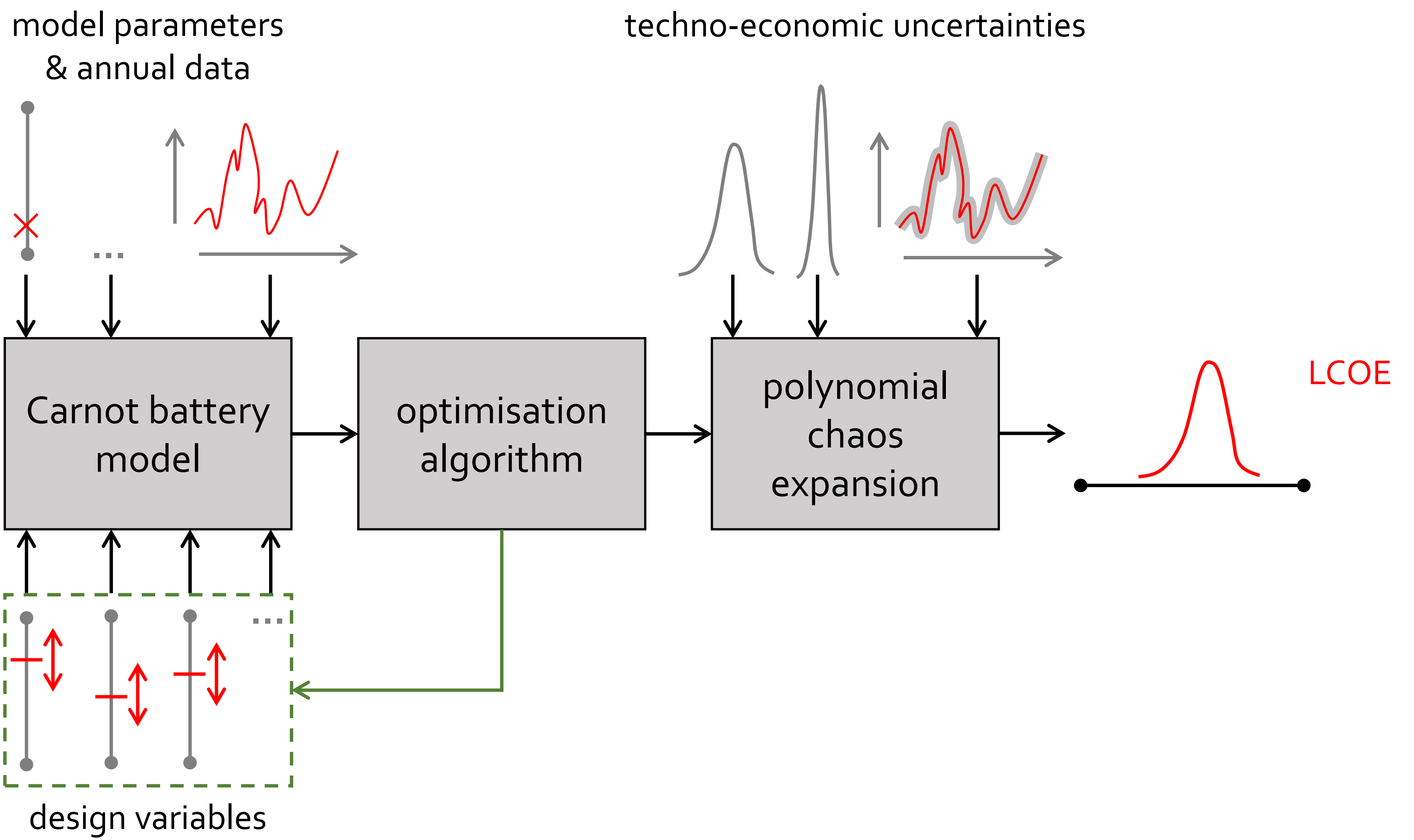
Take away messages

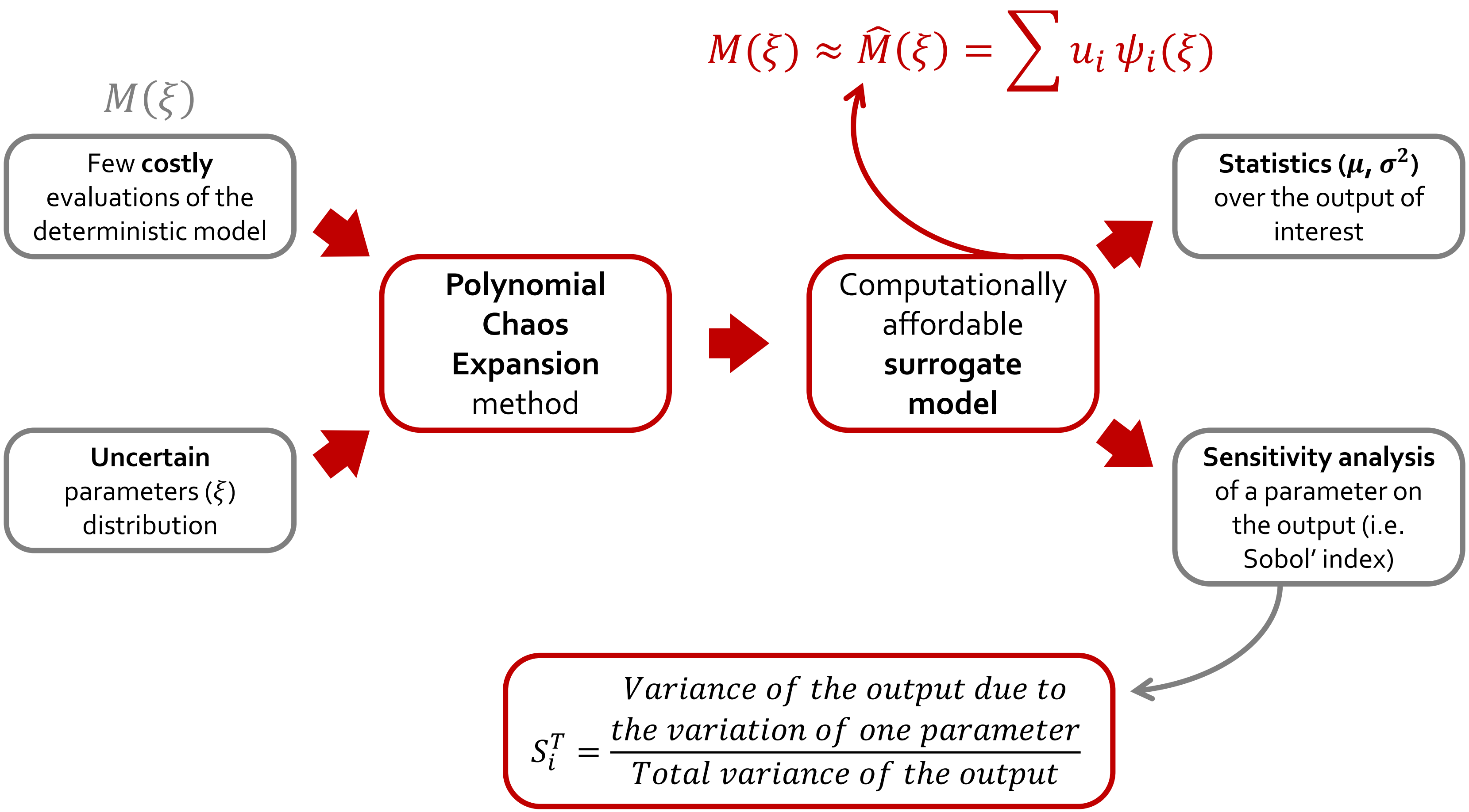
- Integrated approach shows that cost and efficiency are competing objectives;
- Operational constraints are considered (hourly resolution), leading to higher LCOS;
- **Carnot battery can help to reach a SSR of 48.5% for a similar cost;**
- Uncertainty could be reduced with a thinner characterization of the CAPEX and OPEX;
- New designs (e.g. with regenerator) should be explored.

Supplementary material

Summary of the methodology



Polynomial Chaos Expansion: statistics in a tractable time



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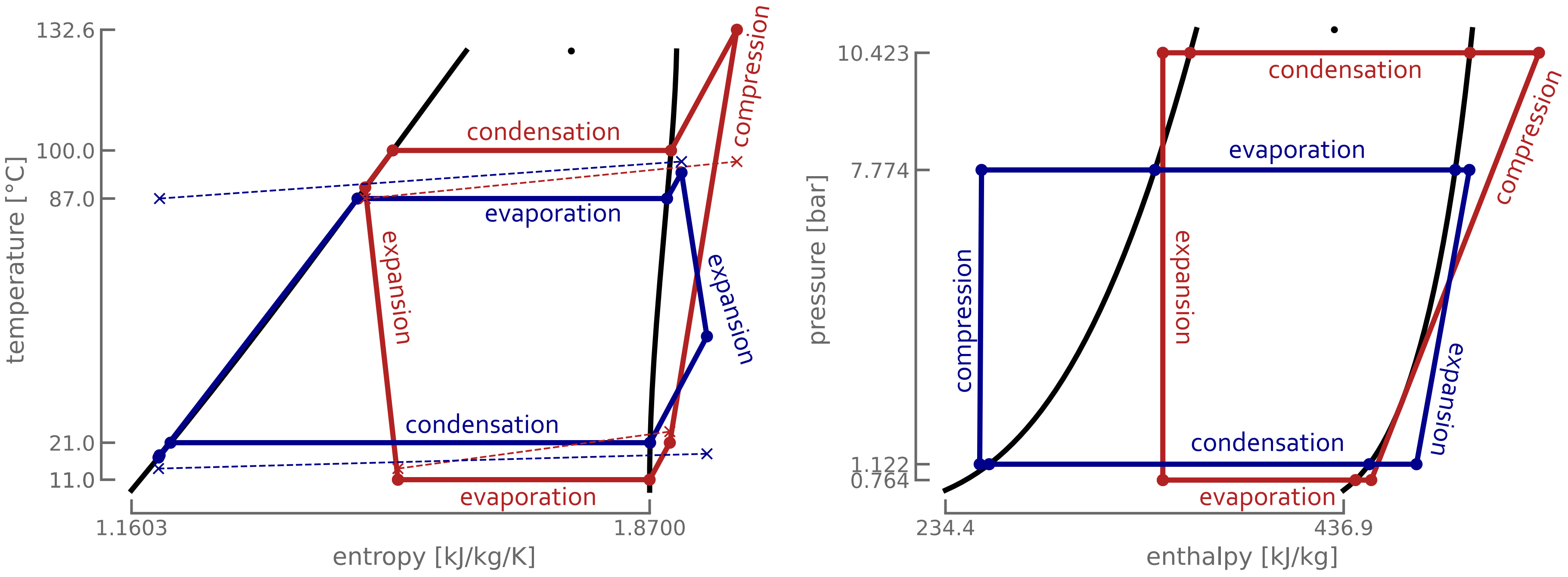
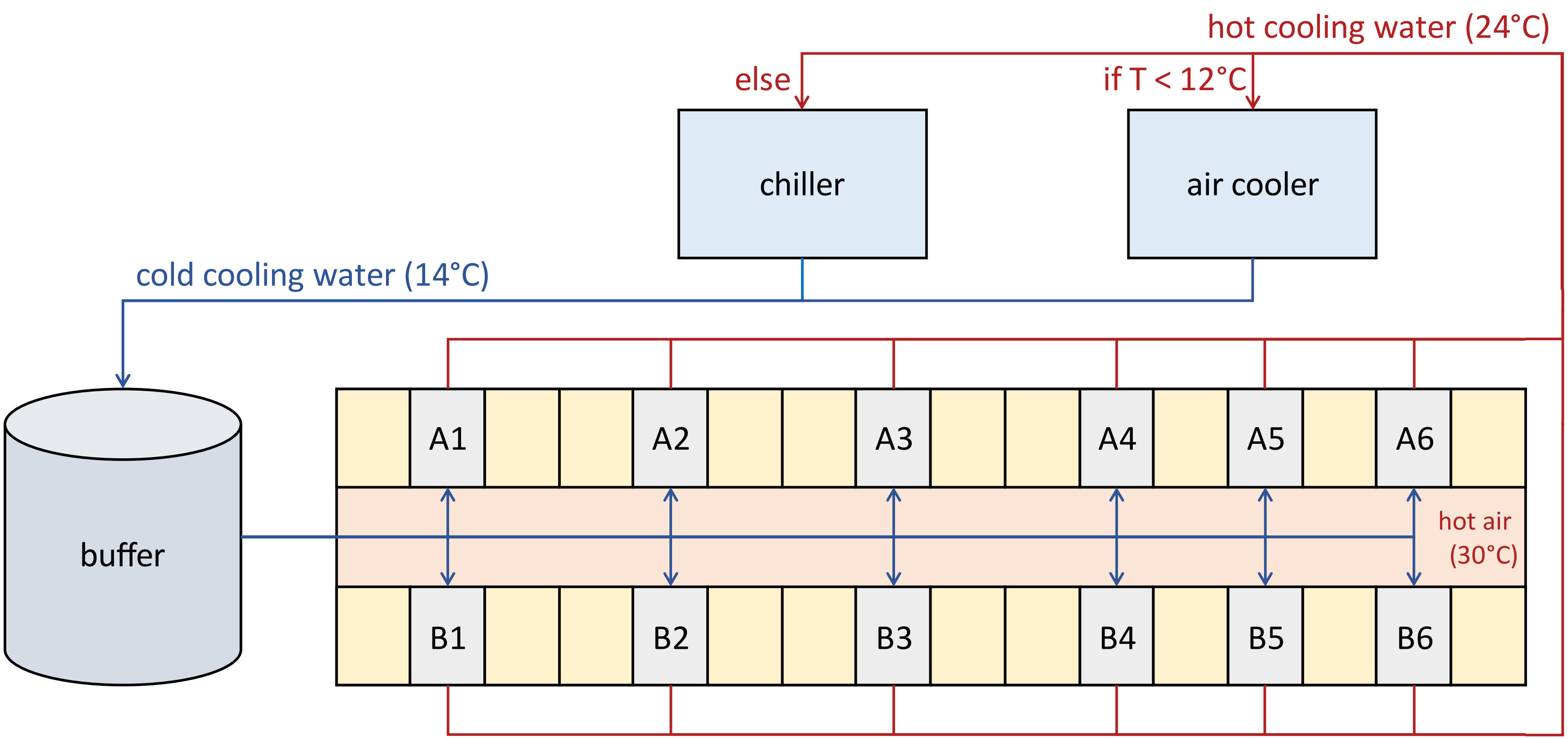
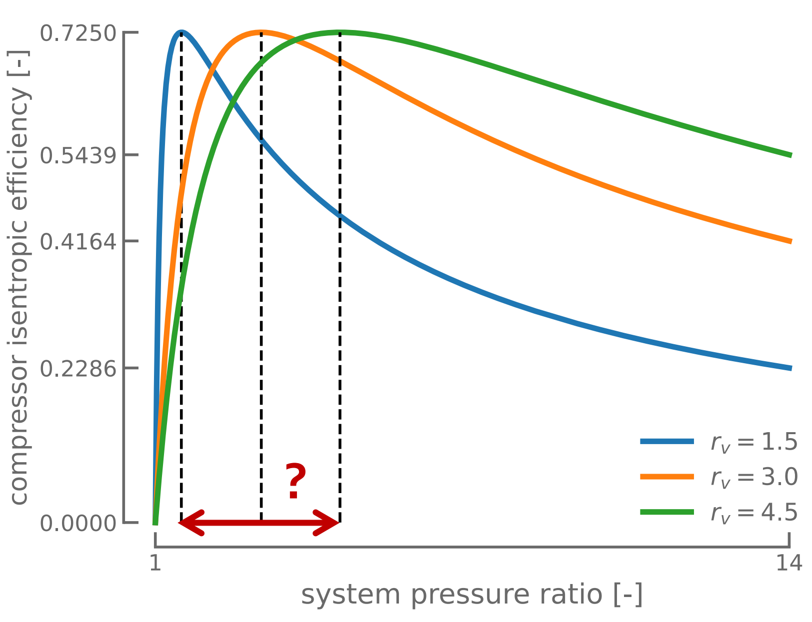
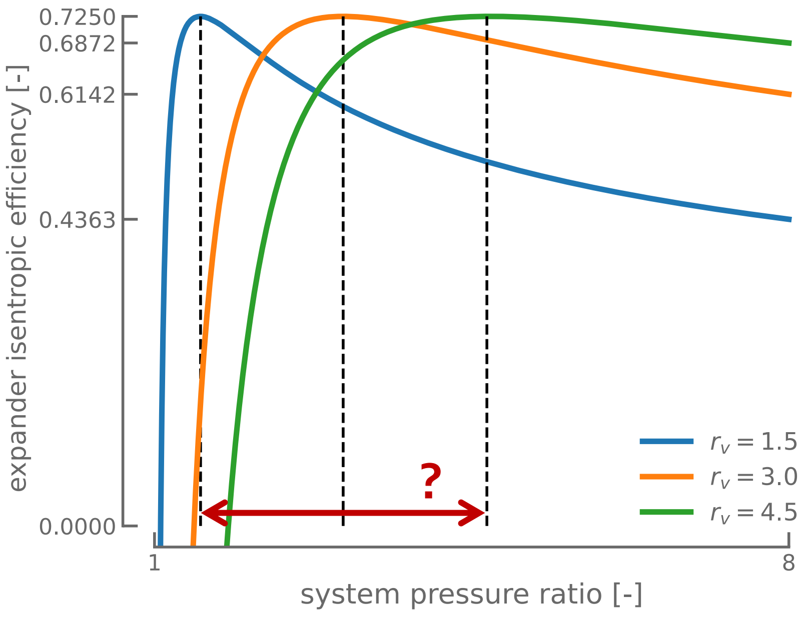


Layout of the UCLouvain data centre



Volume ratio sets location of maximum isentropic efficiency





Designs obtained at the end of the optimisation