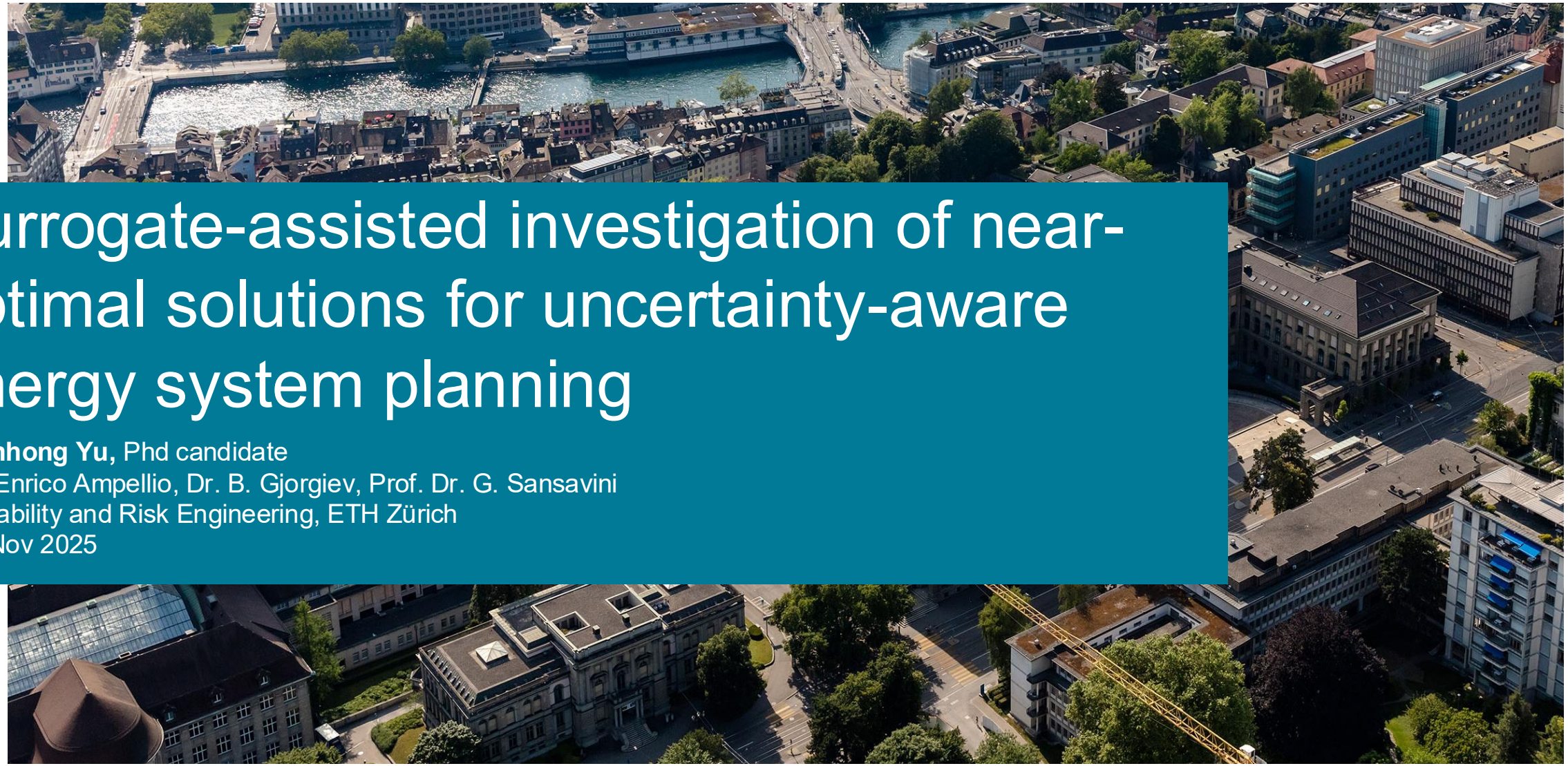
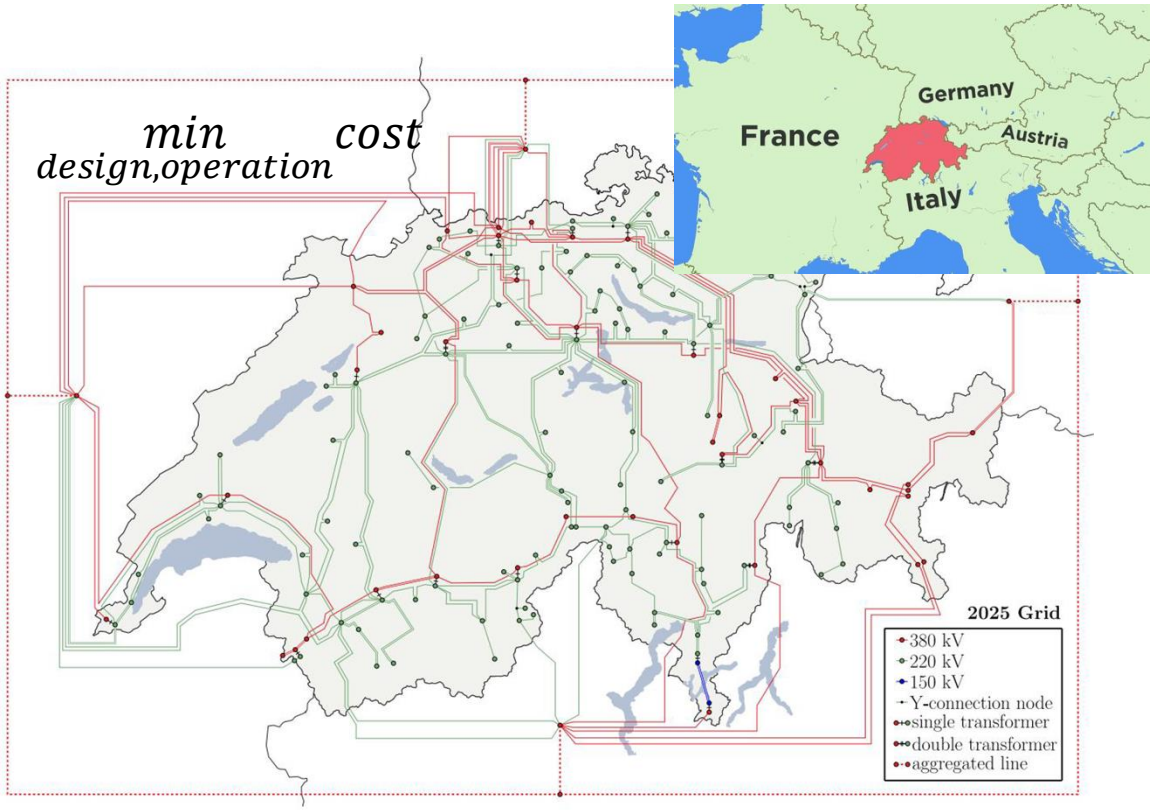


Surrogate-assisted investigation of near-optimal solutions for uncertainty-aware energy system planning

Wanhong Yu, Phd candidate
Dr. Enrico Ampellio, Dr. B. Gjorgiev, Prof. Dr. G. Sansavini
Reliability and Risk Engineering, ETH Zürich
28 Nov 2025

What are the challenges of energy system planning model at transmission level?



Concept overview of the Swiss power system model CentIv [1]

Complex!

CentIv [1]

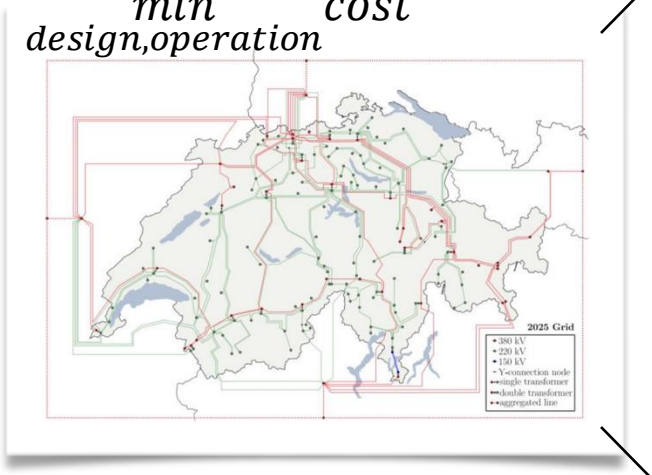
- Optimizes generation expansion and operation decisions for Switzerland and its neighboring countries
- Demand, transmission and reserve requirements
- 169 nodes, 8-hour resolution

=> 4h computation time

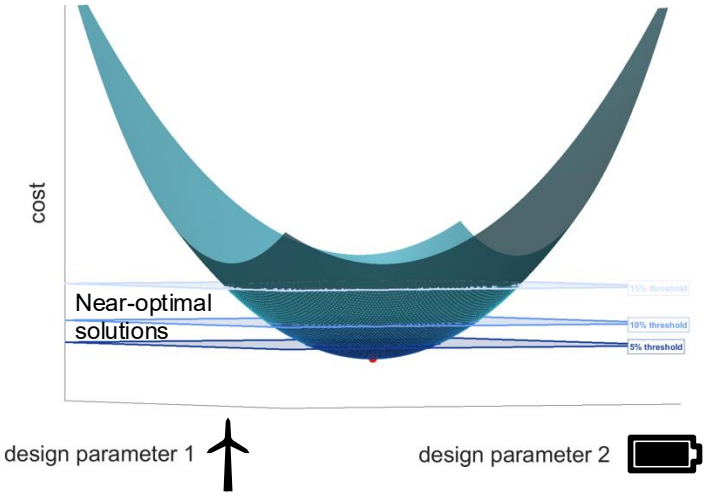
[1] Gjorgiev, B. et al., Nexus-e: A platform of interfaced high-resolution models for energy-economic assessments of future electricity systems. Applied Energy, 177, 118193 (2021).

Uncertainty in energy system planning

$$\min_{design,operation} \; cost$$



Structural uncertainty



Parametric uncertainty

- Technology costs
- Demand and Weather variability
- Sup… tran…

State-of-art methods

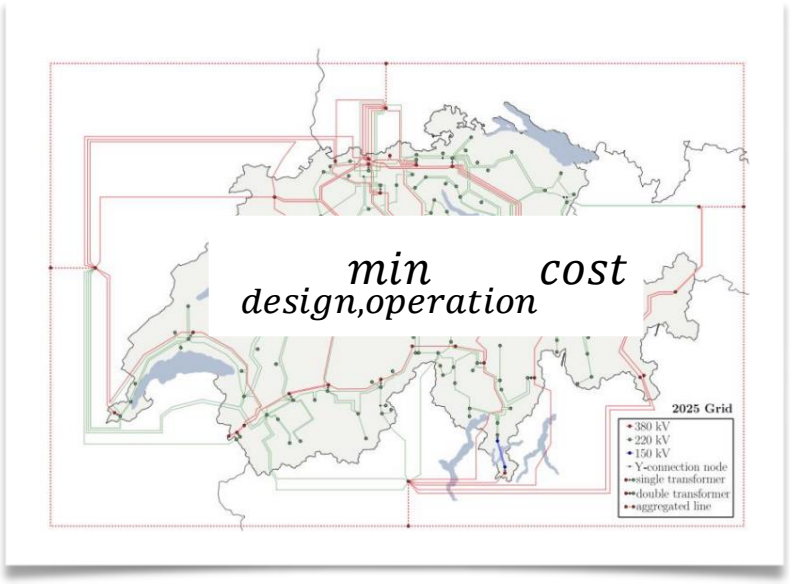
Modelling to generate alternatives (MGA) X sens…

4h X **150** optimization runs for every threshold [1] X **27** scenarios =

[1] Lombardi, F. et al., (2020). Policy decision support for renewables deployment through spatially explicit practically optimal alternatives. *Joule*, *4*(10), 2185-2207.

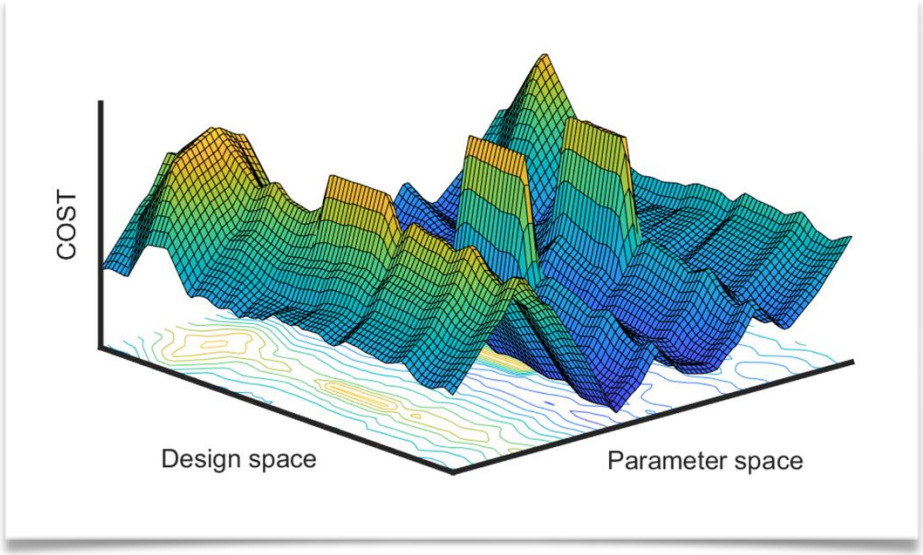
Uncertainty quantification via surrogate model

CentIv



4h

Surrogate model



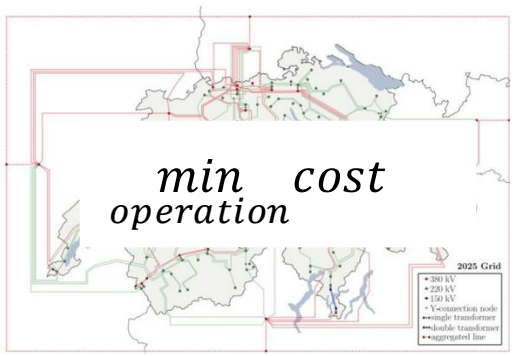
0.01s

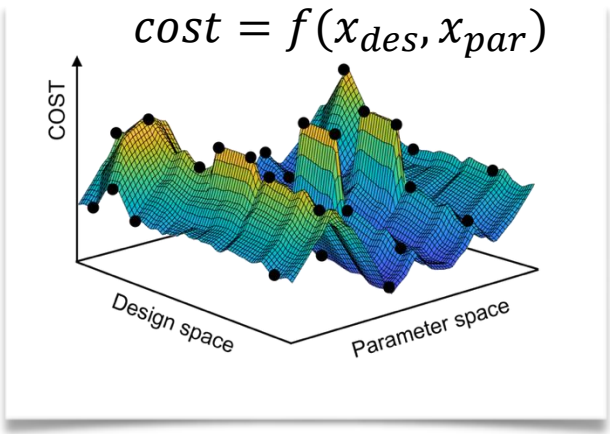
How to learn a model of high fidelity with possibly fewer samples?

Multi-level informed optimization via decomposed Kriging (MLIO)

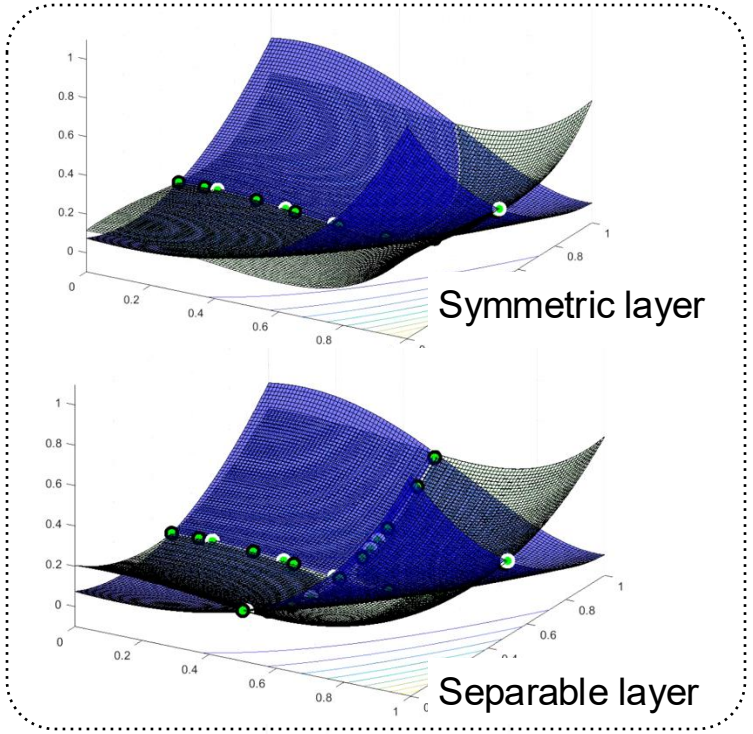
(x_{des}, x_{par})

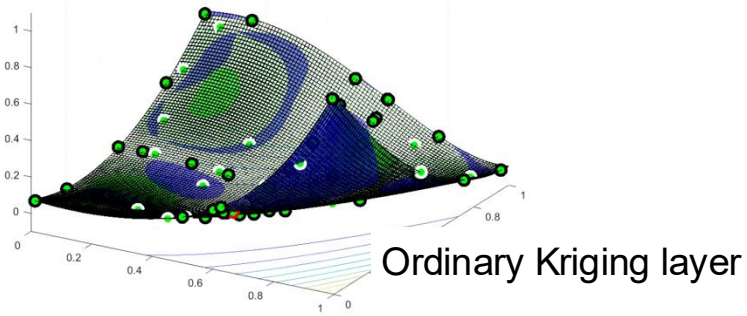
Exploration & Exploitation





cost





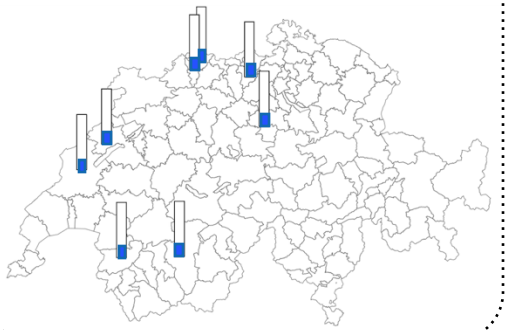
[1] AMPELLIO, E. et al, Multi-level informed optimization via decomposed Kriging for large design problems under uncertainty. *arXiv preprint arXiv:2510.07904*, 2025.

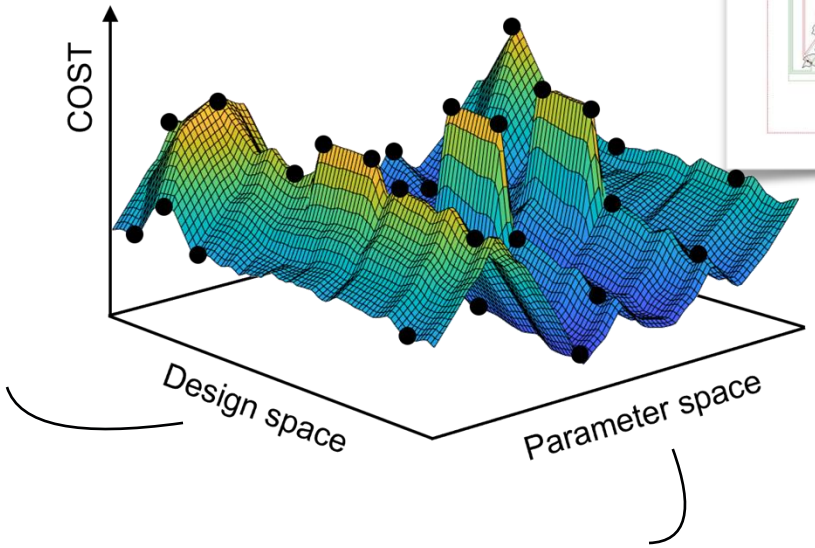
Simplified Case Study

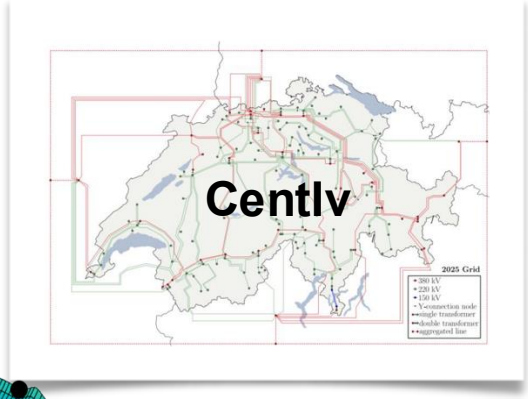
Design space: Expansion of 6 technologies

- WindOn
- Battery
- PV-alpine
- PV-roof
- Gas-CCS
- Gas-Syn

Spatially aggregated







Parameter space

Net transport capacity (NTC) *-70%*

Demand rise *+20%*

default

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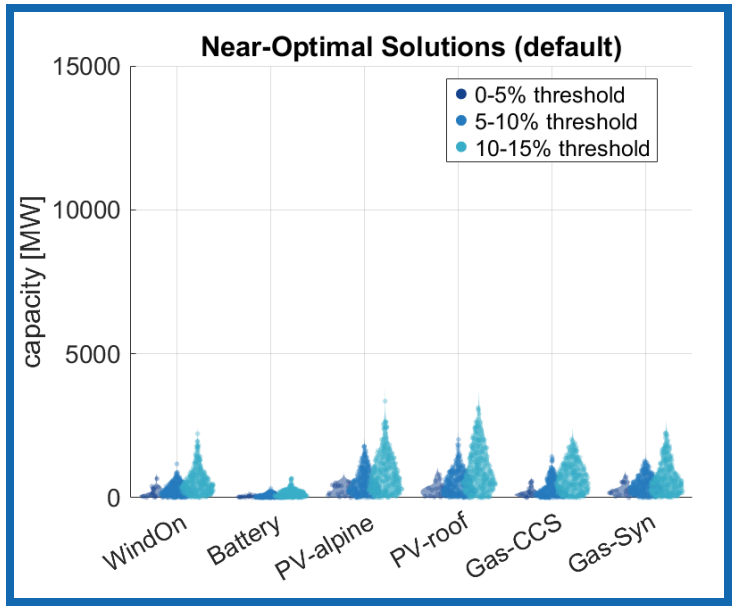
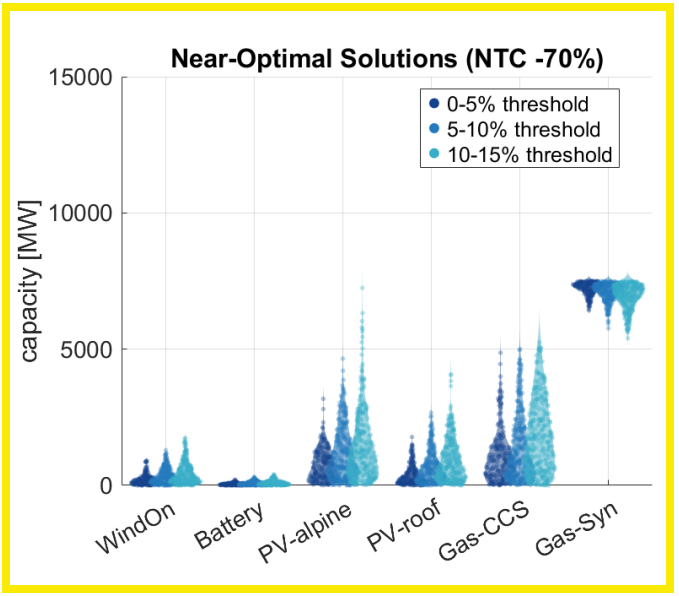
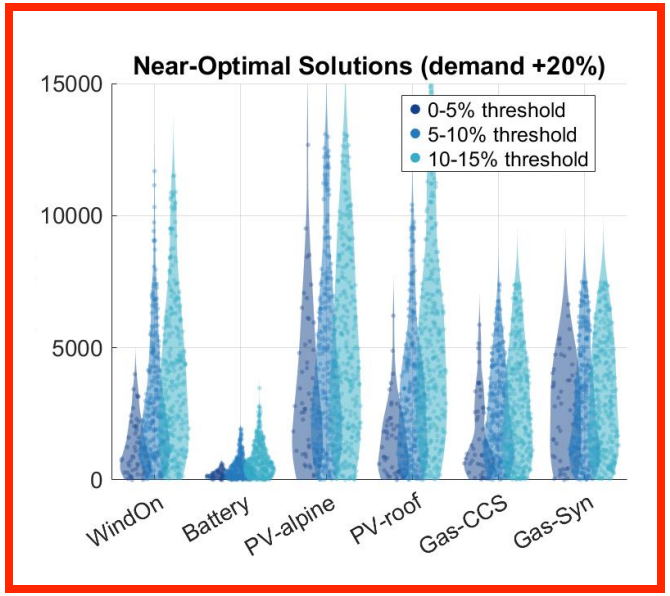
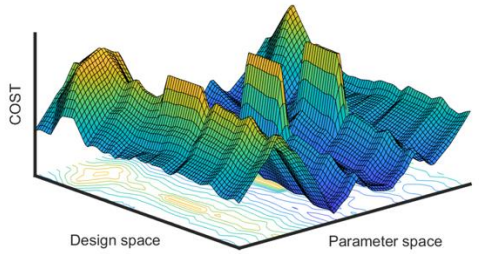
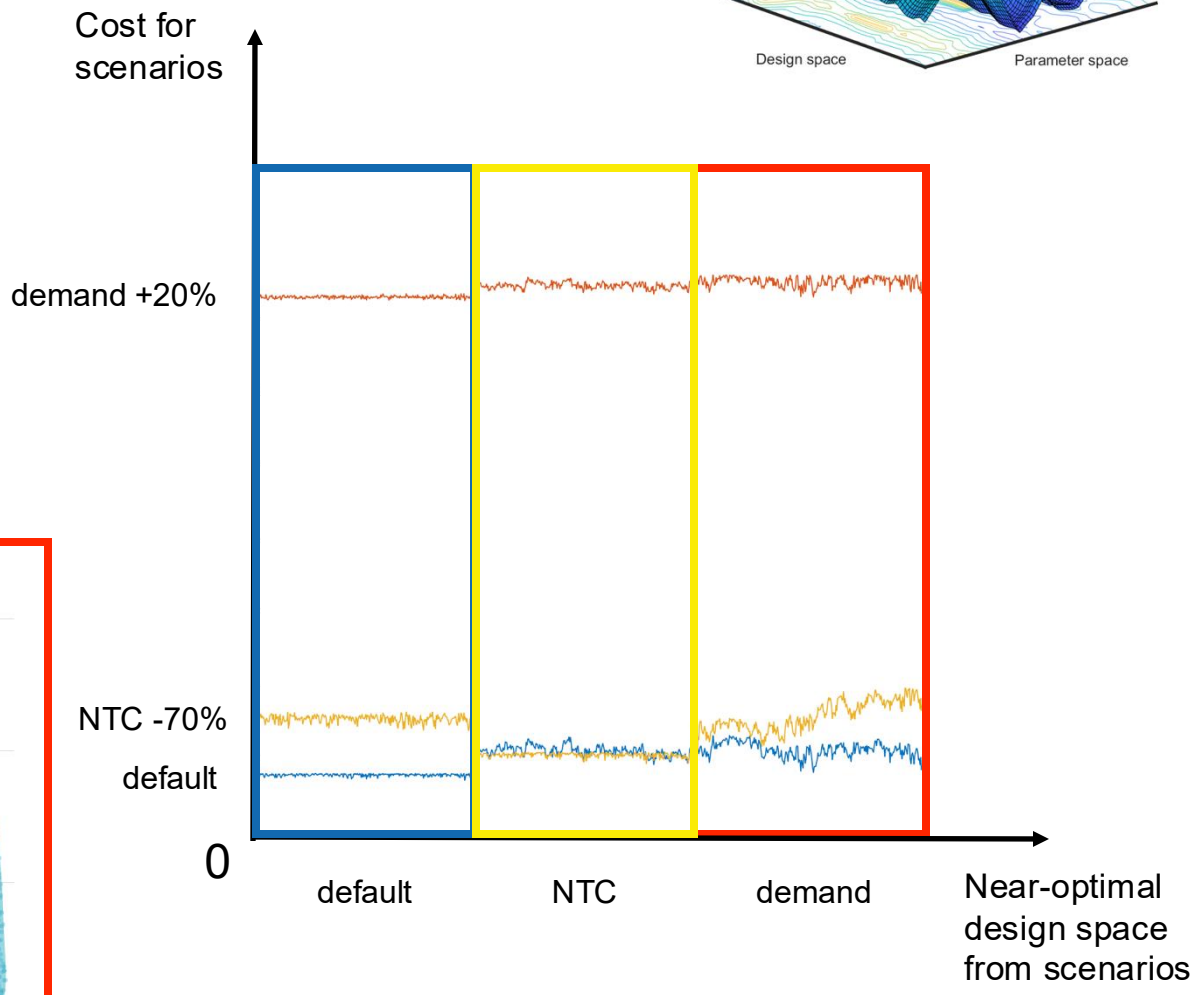
Preliminary results: near-optimal solutions for different scenar











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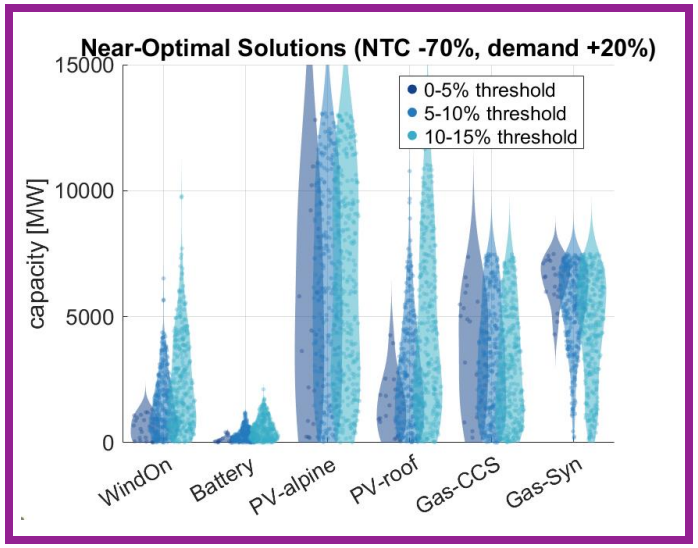
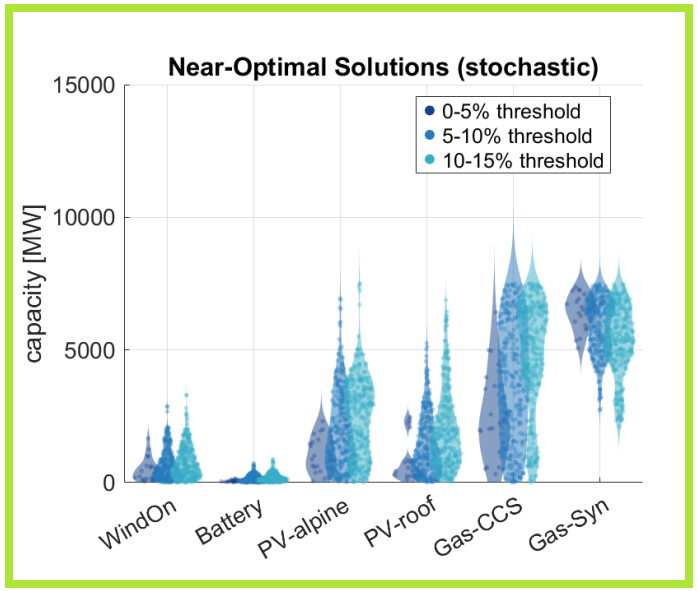
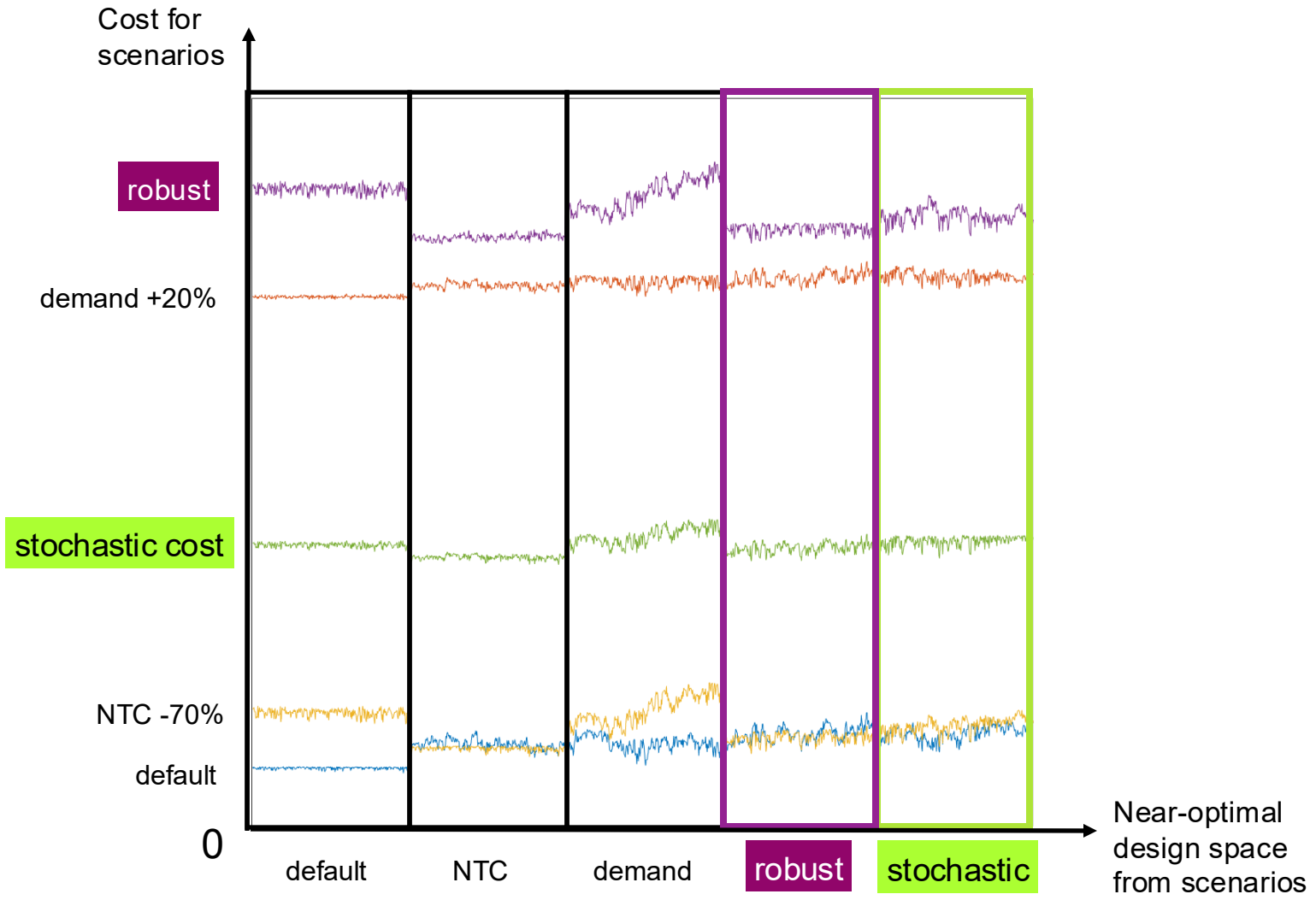
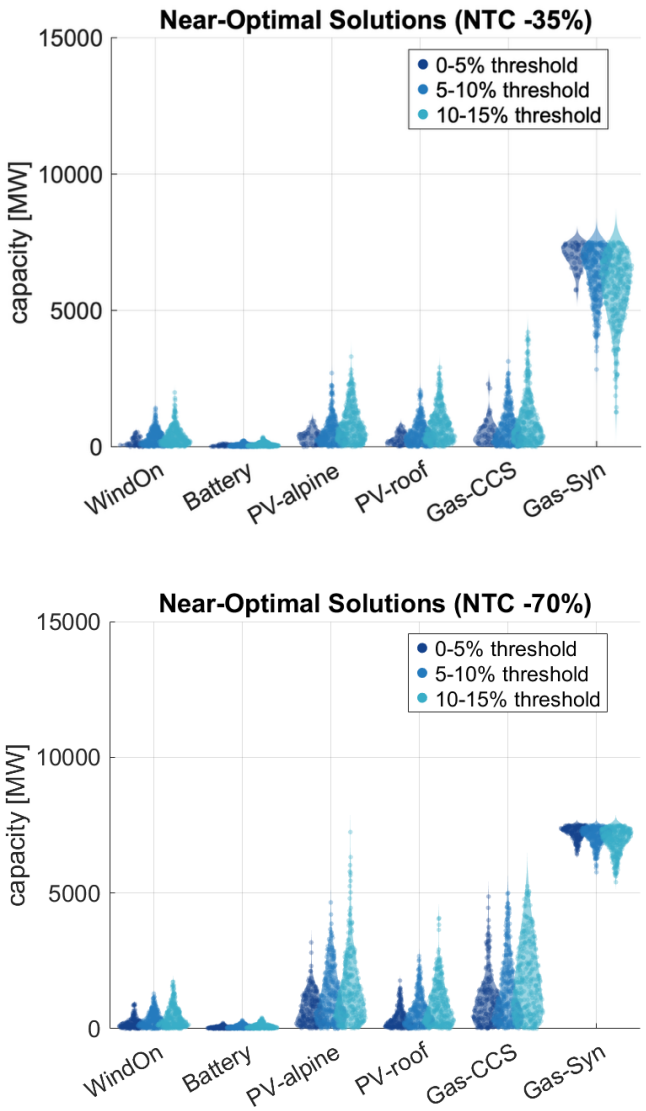
Preliminary results: near-optimal robust and stochastic solutions

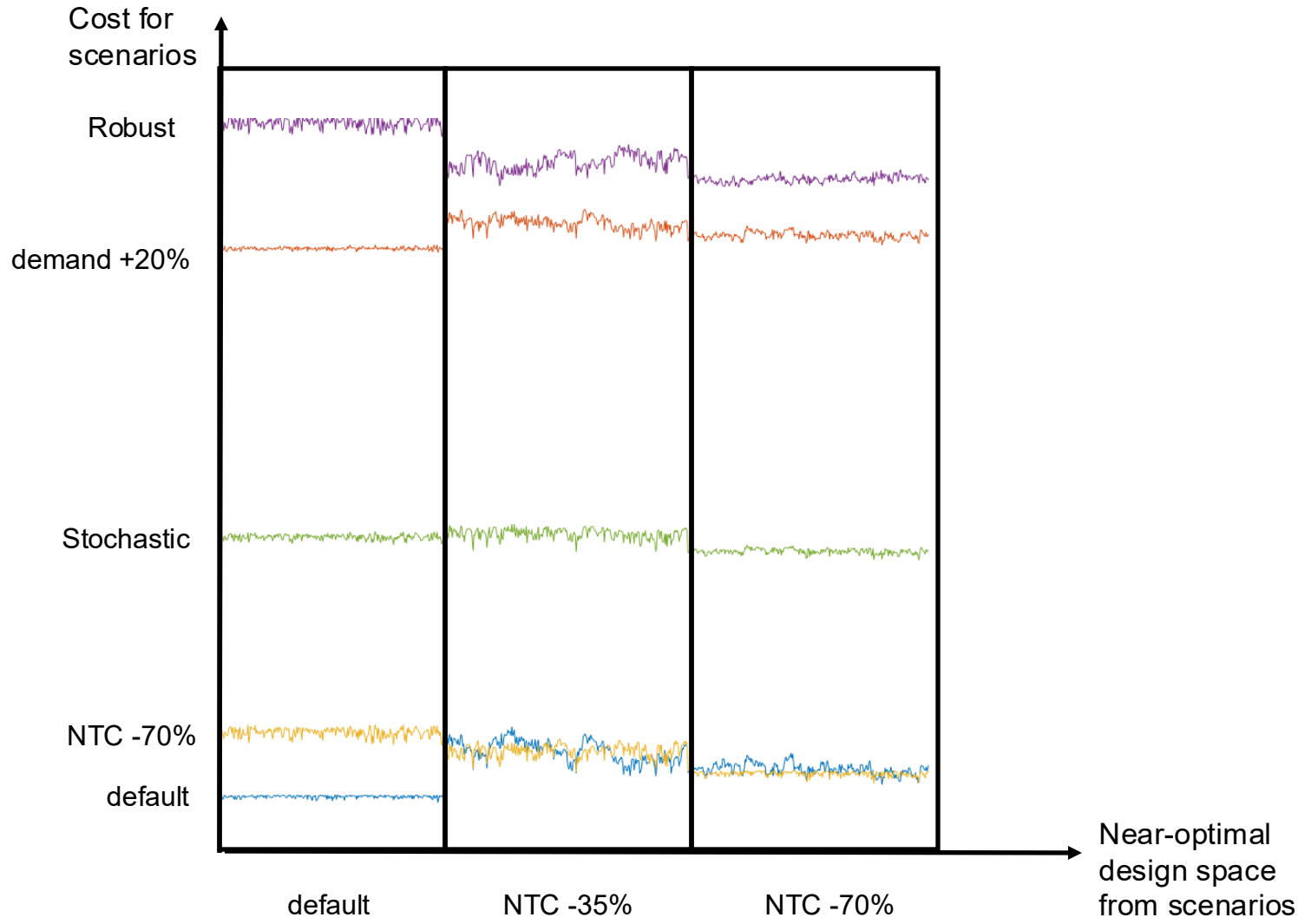






Preliminary results: effect of NTC levels on near-optimal solution space

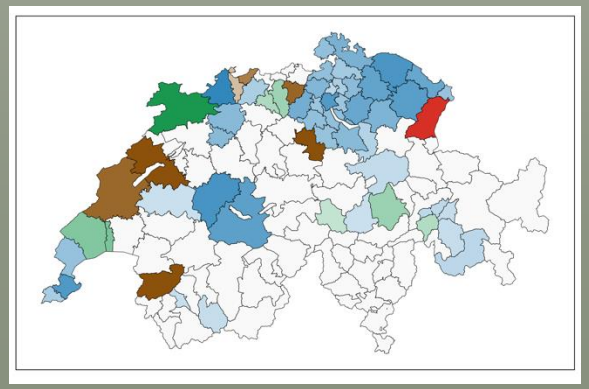




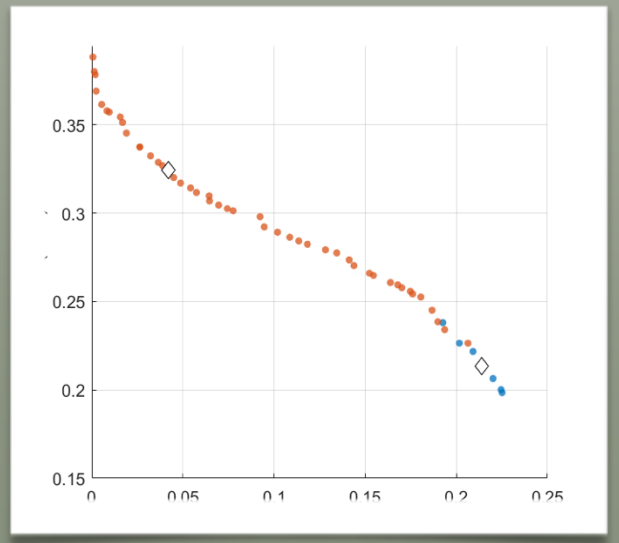
Next steps

Add **more granuality** on design and parameter space

- Spatially
- Temporally
- Impact of fuel and technology cost variability



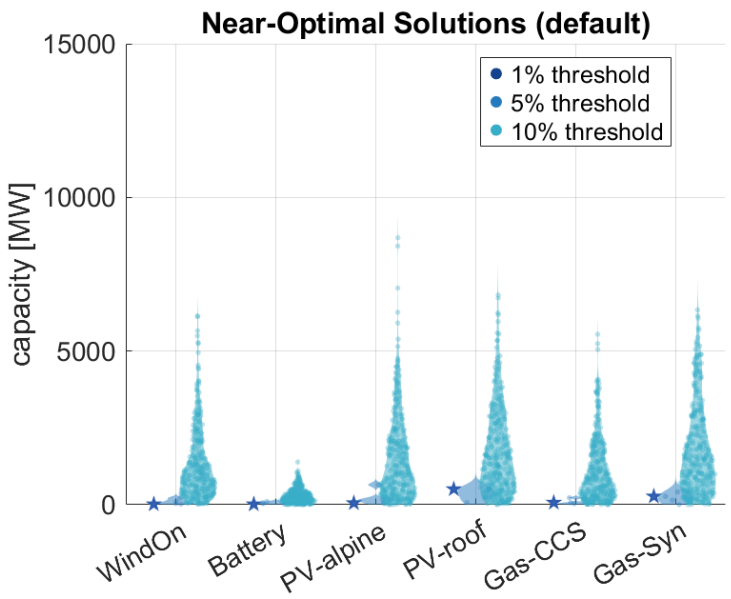
Multi-objectives for import and demand-not-served

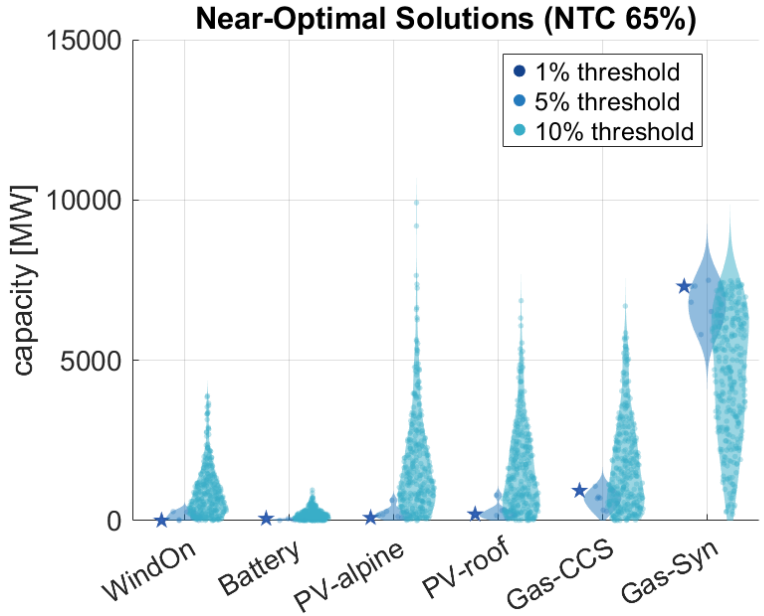


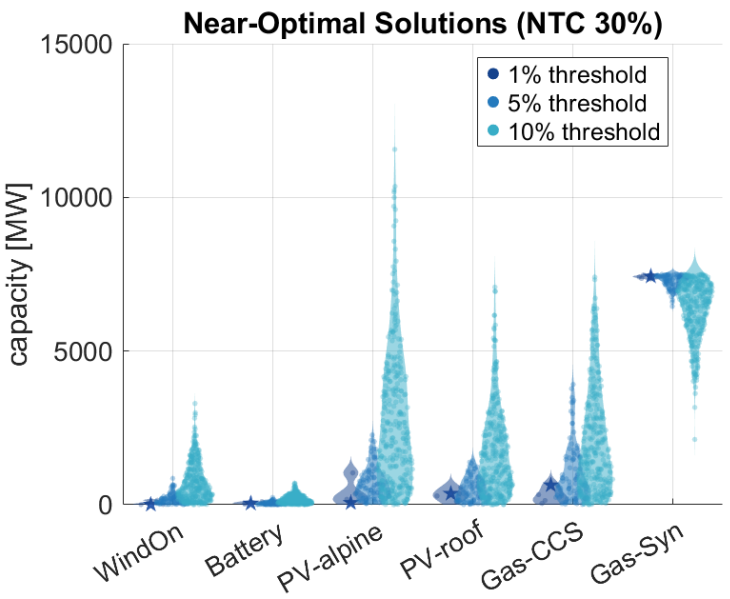
Thank you very much for your attention!

Since here are useless backups

Preliminary results: effect of NTC







Preliminary results: effect of demand