Cost sensitivity of optimal sector-coupled district heating production systems

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Motivation

Simulation:

<u>Good:</u> Explore ideas where the cost is: Highly uncertain or different for different people.

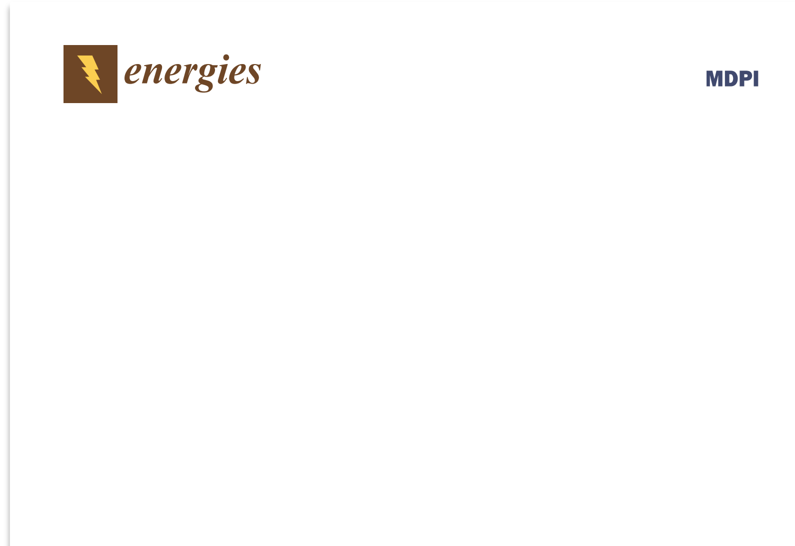
<u>Bad:</u> Operator bias is very likely to occur and scenarios are hard to compare.

vs

Optimization:

<u>Good:</u> Consistent method to pick a complex solution. Well defined cost function.

<u>Bad:</u> Operator bias is very likely to occur costs can difficult to include in a meaningful way.



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Scenario based optimization
Make a few *important* choices and let the optimizer figure out the details.

Agenda

- Use the Aarhus case to discuss sensitivity analysis.

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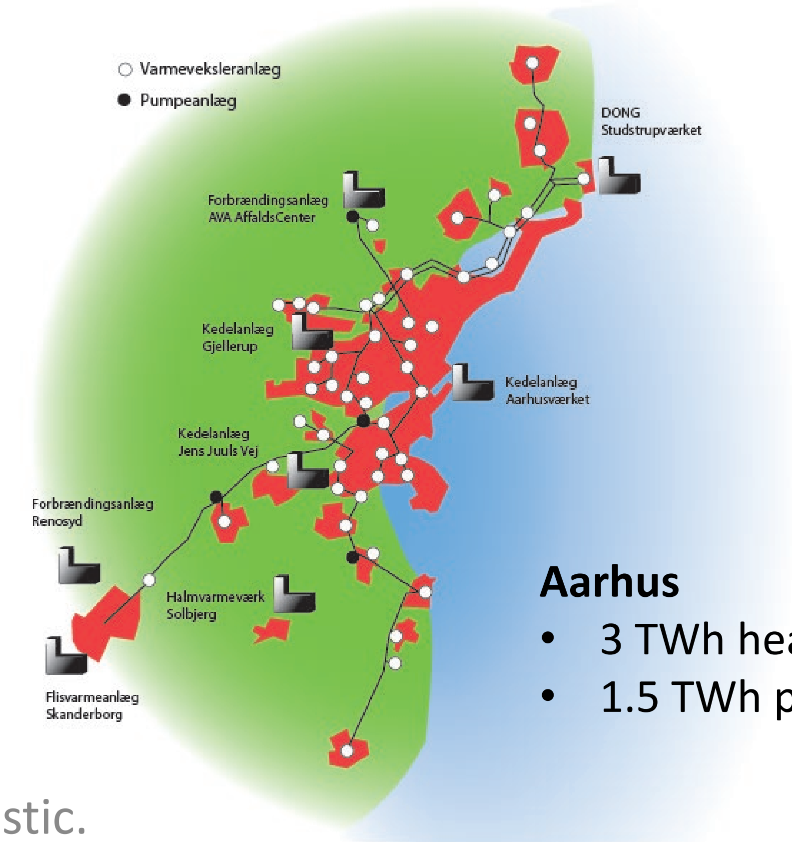
A B S T R A C T

Goals to reduce carbon emissions and changing electricity prices due to increasing penetrations of wind power generation affect the planning and operation of district heating production systems. Through extensive multivariate sensitivity analysis, this study estimates the robustness of future cost-optimal heat production systems under changing electricity prices, fuel cost and investment cost. Optimal production capacities are installed choosing from a range of well-established production and storage technologies including boilers, combined heat and power (CHP) units, power-to-heat technologies and heat storages. The optimal heat production system is characterized in three different electricity pricing scenarios: Historical, wind power dominated and demand dominated. Coal CHP, large heat pumps and heat storages dominate the optimal system if fossil fuels are allowed. Heat pumps and storages take over if fossil fuels are excluded. The capacity allocation between CHP and heat pumps is highly dependent on cost assumptions in the fossil fuel scenario, but the optimal capacities become much more robust if fossil fuels are not included. System cost becomes less robust in a fossil free scenario. If the electricity pricing is dominated by wind power generation or by the electricity demand, heat pumps become more favorable compared to cogeneration units. The need for heat storage more than doubles, if fossil fuels are not

Read more: https://doi.org/10.1016/j.energy.2018.10.044



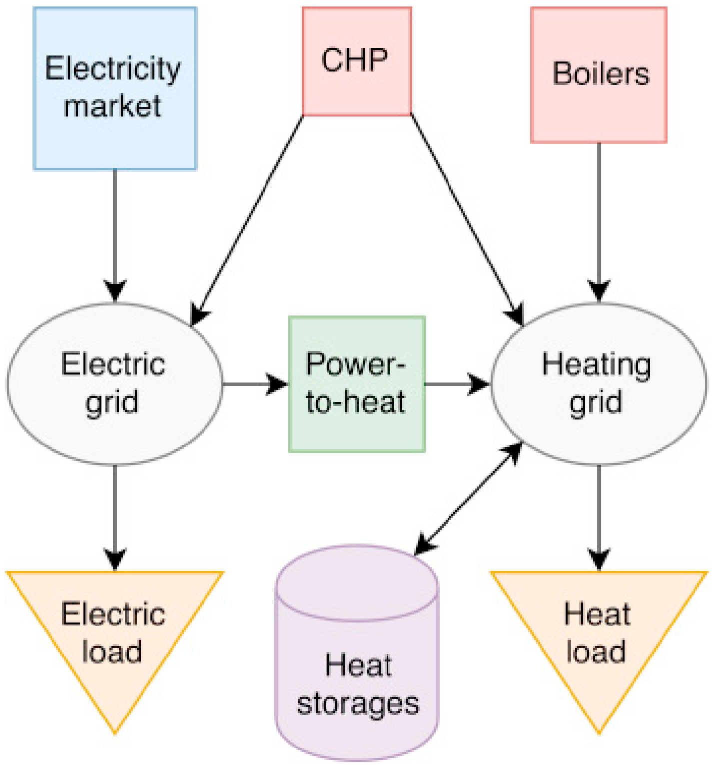
Aarhus

- 3 TWh heat
- 1.5 TWh power

The case keeps the model realistic.

MODEL DESIGN & VALIDATION

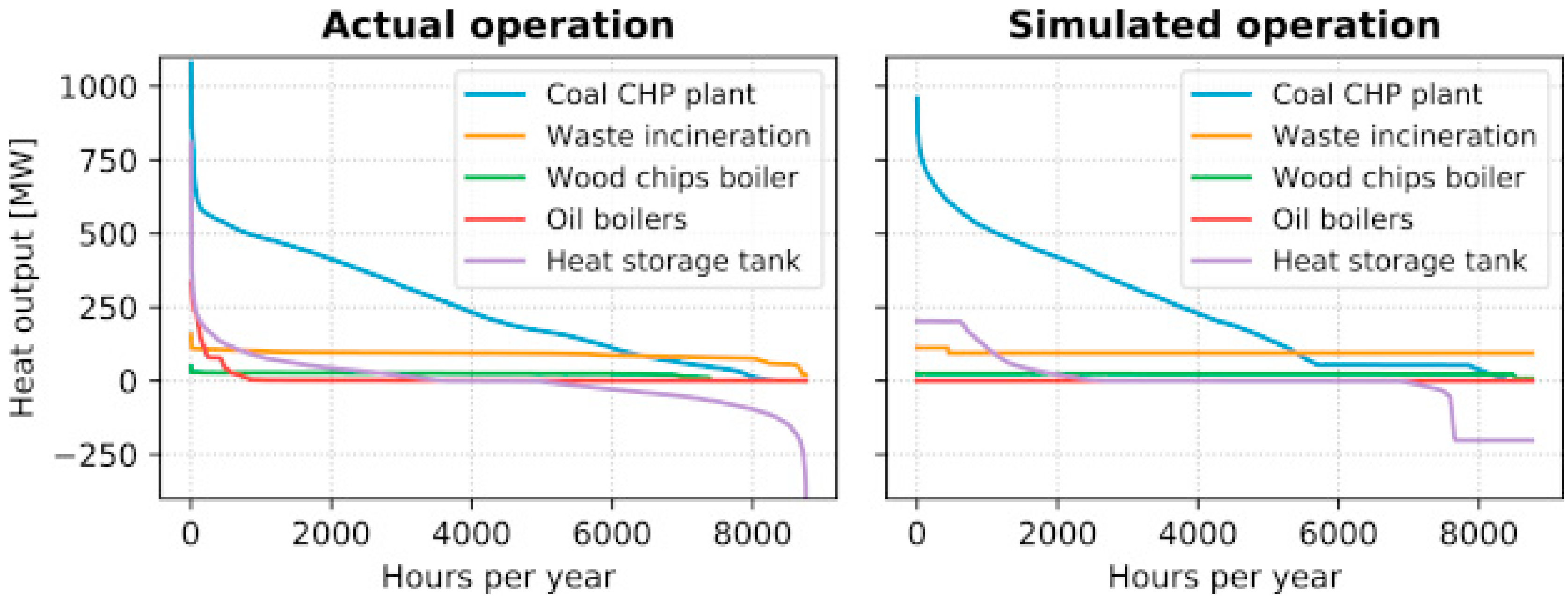
Model description



- Hourly simulation of one full year.
- Fairly detailed representation of technologies.
- Optimal dispatch.
- Capacity optimization.
- Taxes and regulations are not included.

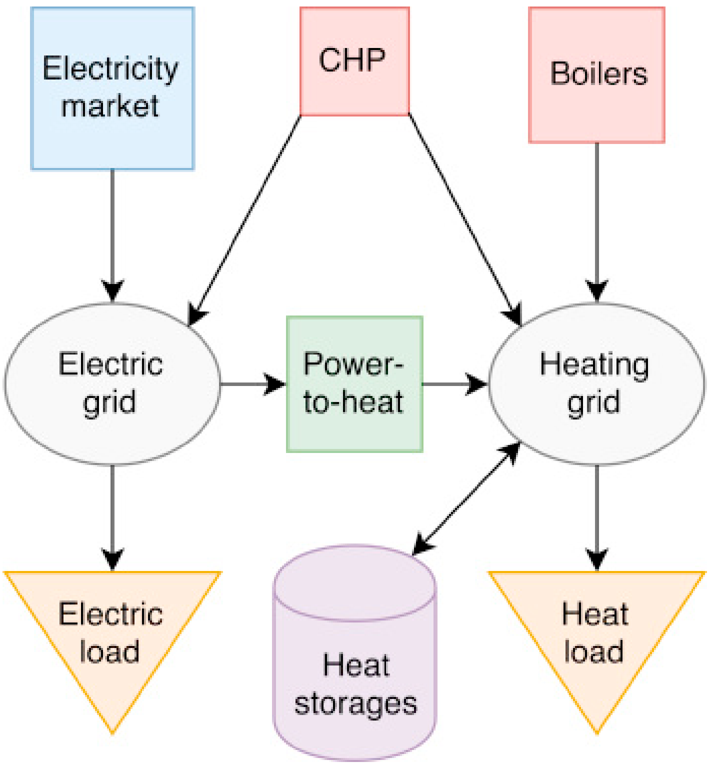
The model was implemented in the PyPSA framework (see pypsa.org).

Model validation (2015)



- Differences between model and simulation can mostly be explained by planned and unplanned shut-down of various units.

Combined investment and operational optimization



Investment costs

$$\min_{\overline{P}_u^{\text{el}},\overline{P}_u^{\text{heat}},\overline{H}_s,\, P_{u,t}^{\text{el}},P_{u,t}^{\text{heat}},} \left(\sum_{u \in \text{prod. units}} c_u^{\text{el}} \overline{P}_u^{\text{el}} + c_u^{\text{heat}} \overline{P}_u^{\text{heat}} + \sum_{s \in \text{storages}} c_s^{\text{stor}} \overline{H}_s + \sum_{t=1}^{N} \Delta t \left[\sum_{u \in \text{prod. units}} o_{u,t}^{\text{el}} P_{u,t}^{\text{el}} + o_{u,t}^{\text{heat}} P_{u,t}^{\text{heat}} + \sum_{s \in \text{storages}} o_{s,t}^{\text{disp}} h_{s,t} + o_{s,t}^{\text{upt}} f_{s,t} \right] \right)$$

Operational costs

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Available technologies

Boilers
- Wood chips
- Gas
- Oil

Combined heat and power
- Wood pellets
- Gas (simple cycle)
- Gas (combined cycle)
- Gas engines
- Coal
- Straw

Power-to-heat
- Electric boilers
- Compression heat pumps

Heat storage
- Storage tanks
- Storage pits

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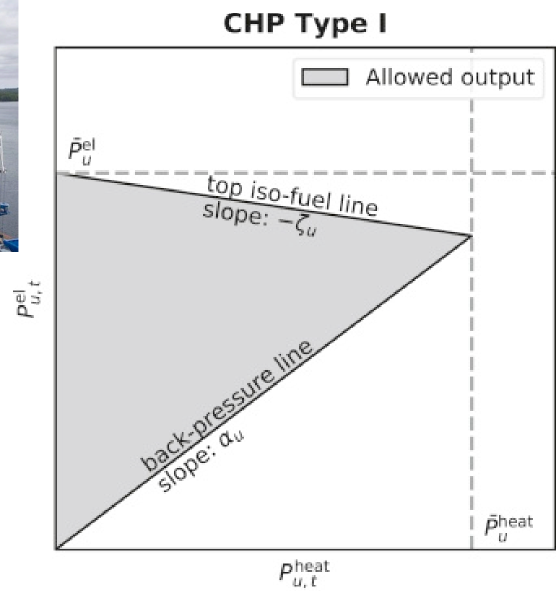

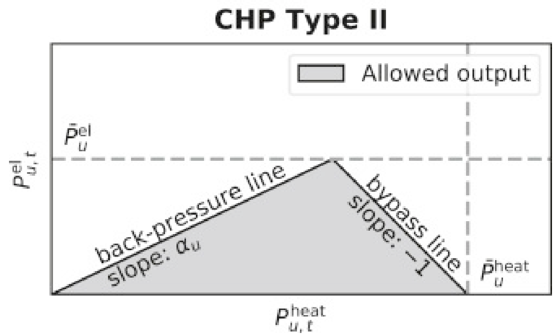

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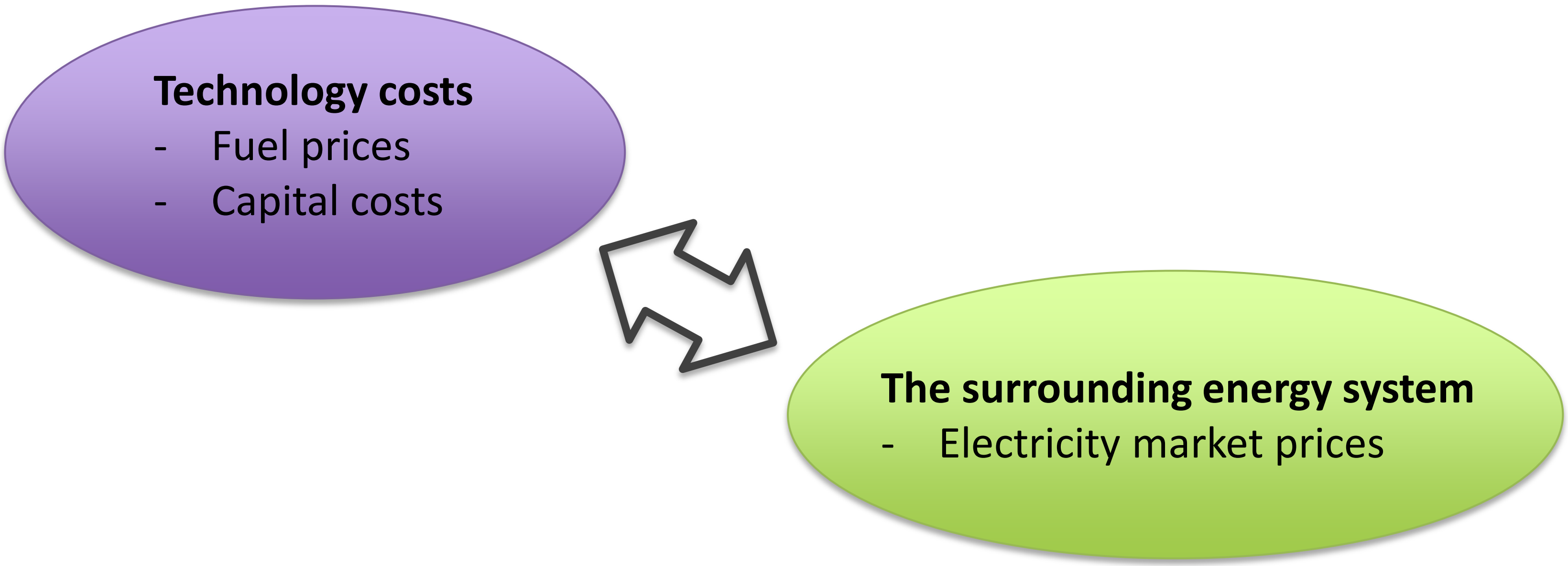


How different are the *optimal* solutions?

SCENARIOS AND RESULTS

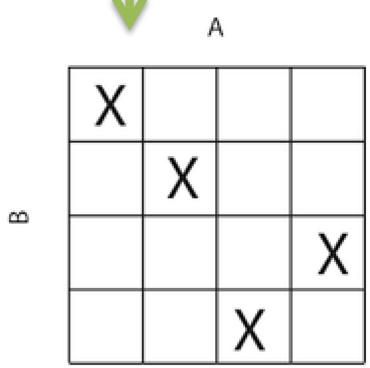
Multivariate cost variations

Technology costs
- Fuel prices
- Capital costs

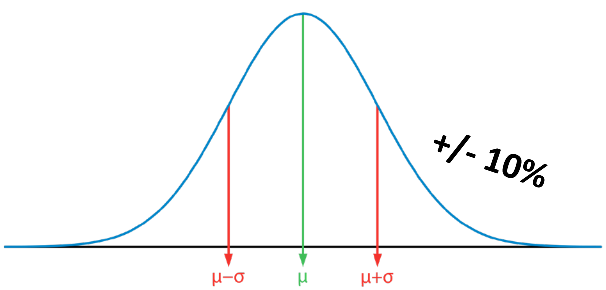
(a) Boiler technologies (fuel based).

Boiler type	Fuel cost	CapEx	$OpEx_{fixed}$	$OpEx_{variable}$	Lifetime	η^{boiler}
	[€/MWh_{fuel}]	[M€/MW_{heat}]	[k€/MW_{heat}/yr]	[€/MWh_{heat}]	[yr]	[−]
Wood chips	24	0.8	0	5.4	20	1.08
Gas	20	0.06	2	1.1	25	1.03
Oil	46	0.06	2	0.26	25	0.94

All fuel and investment costs



Latin hyper cube sampling



Gaussian probability distribution

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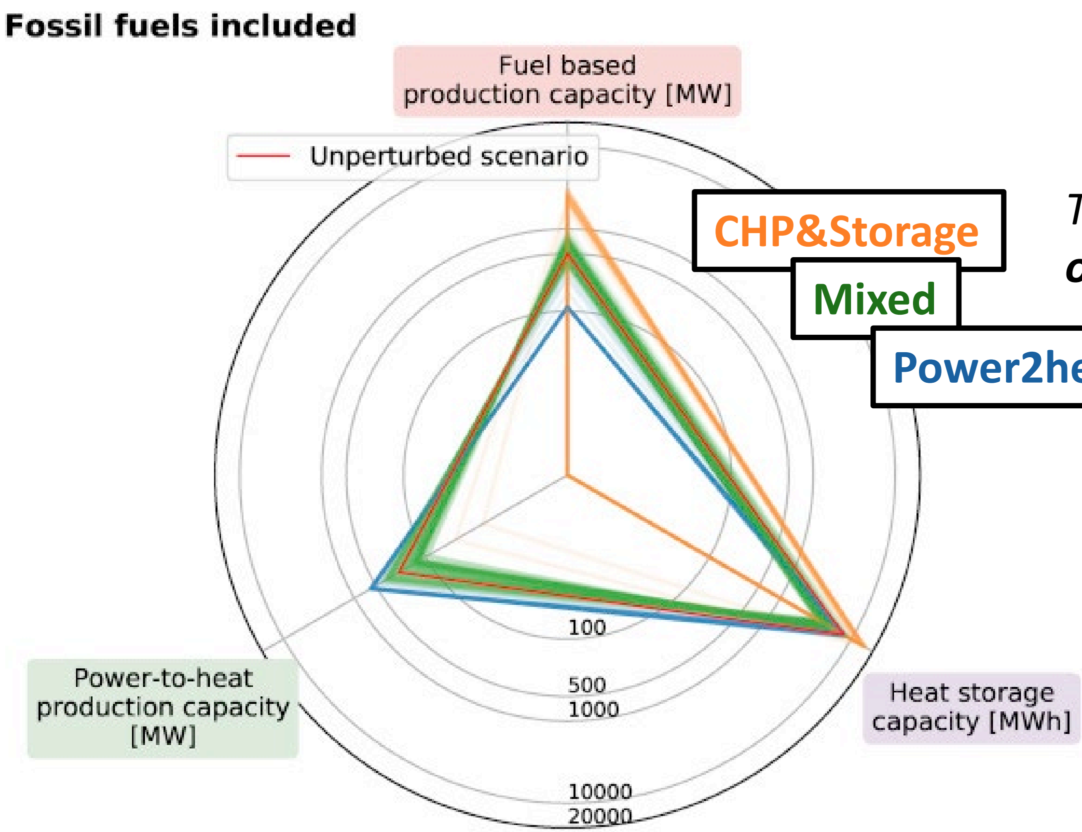
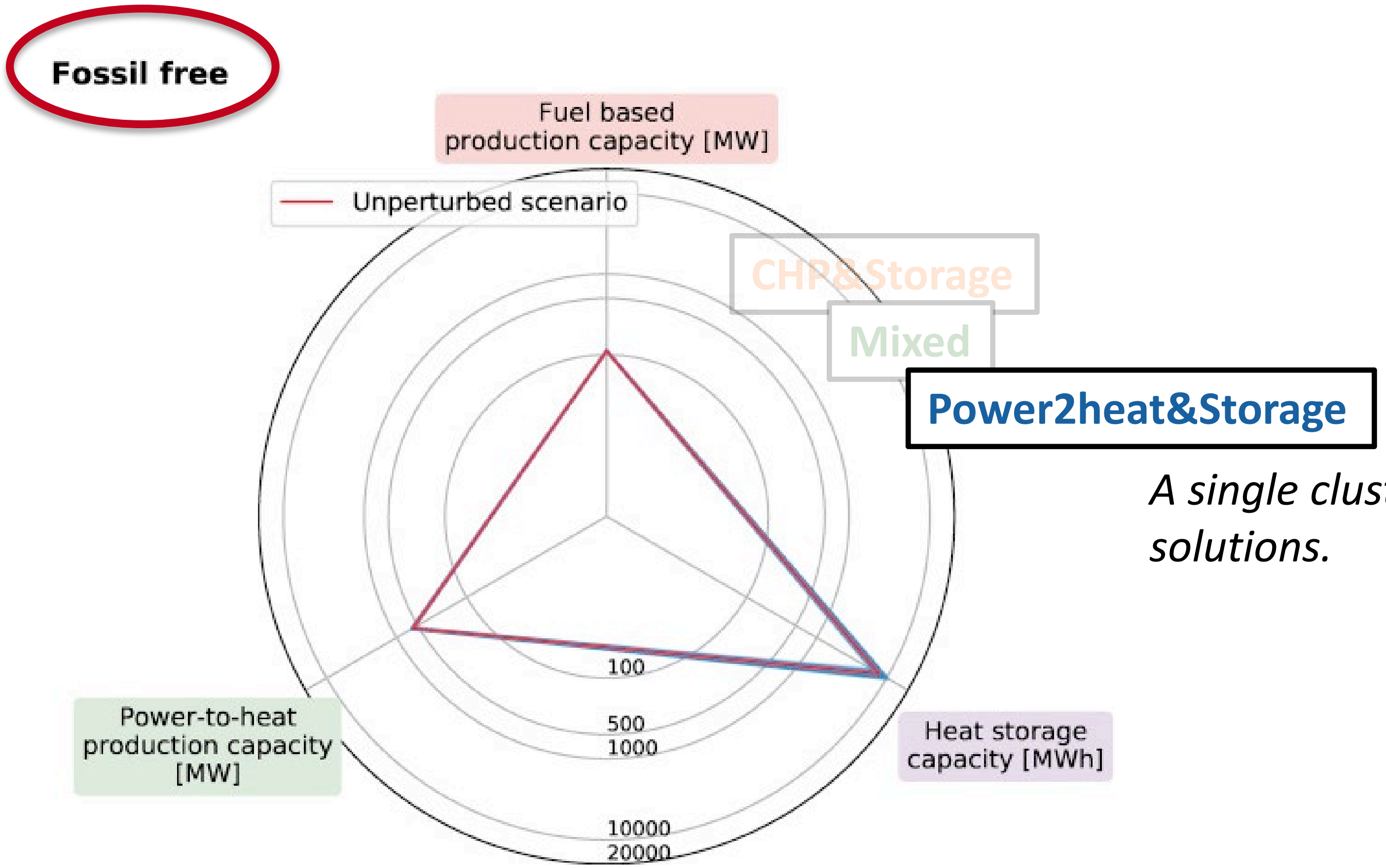
200x scenario: All technologies



Three different clusters of ***optimal*** *solutions.*

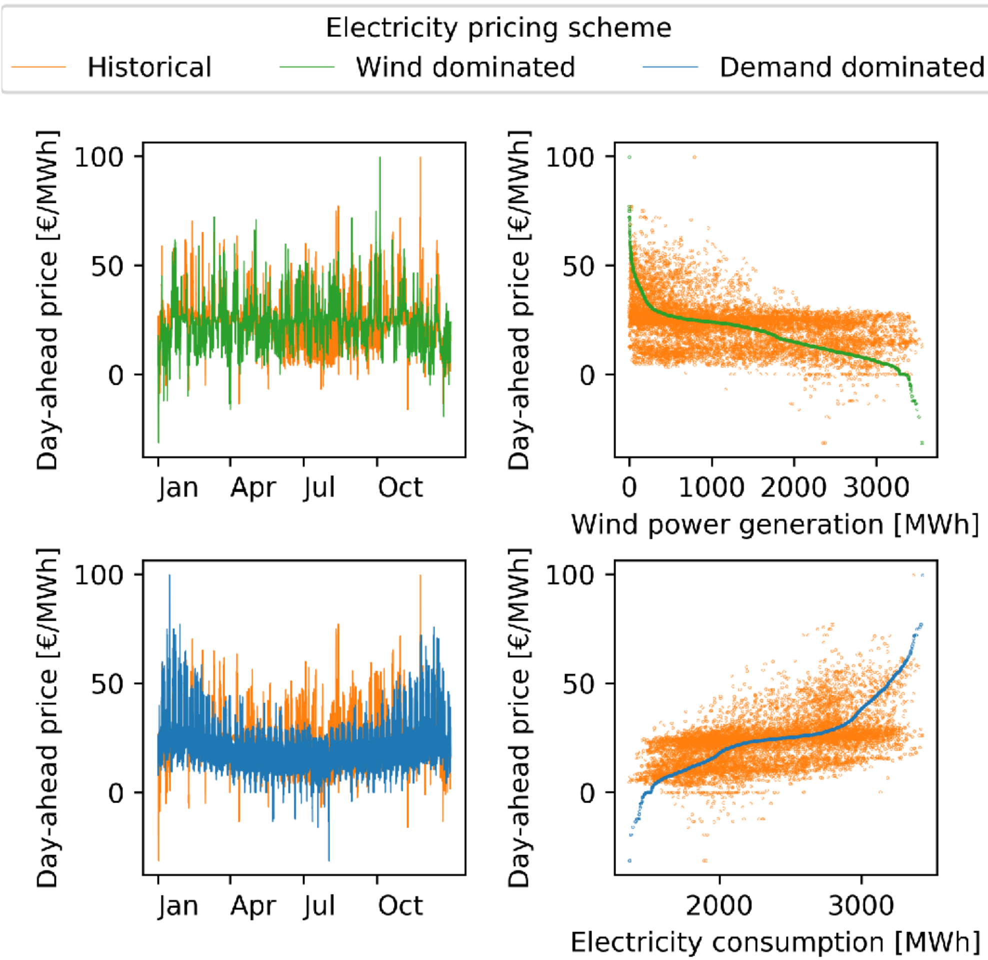
200x scenario: Fossil free



*A single cluster of **optimal** solutions.*

Electricity price scenarios

The surrounding energy system
- Electricity market prices



A. Historical market price (2015)

B. Wind dominated

Lowest price goes with highest wind and vice versa.

C. Demand dominated

Highest price goes with highest demand and vice versa.

All moments of the price distribution are conserved. This allows for a direct comparison.

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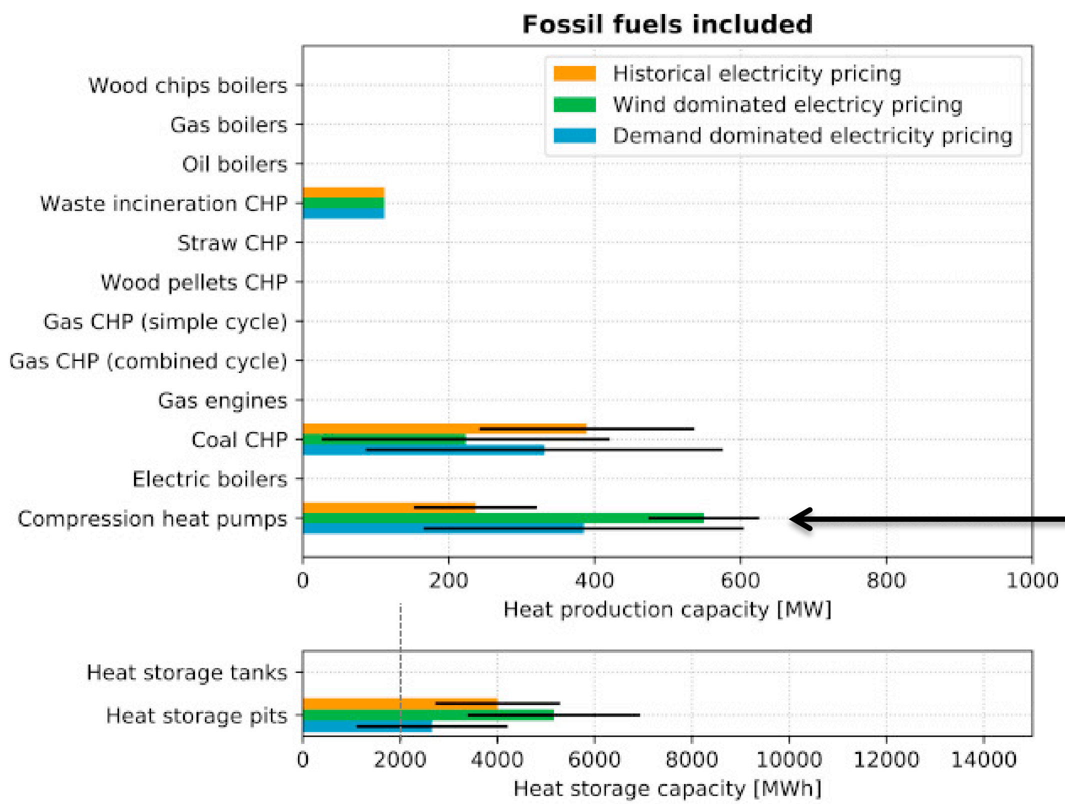
Electricity price scenarios: Results



- Similar *optimal* technologies are identified for all price scenarios.
- Optimal capacities are quite uncertain.

Error bars represent 1 standard deviation.

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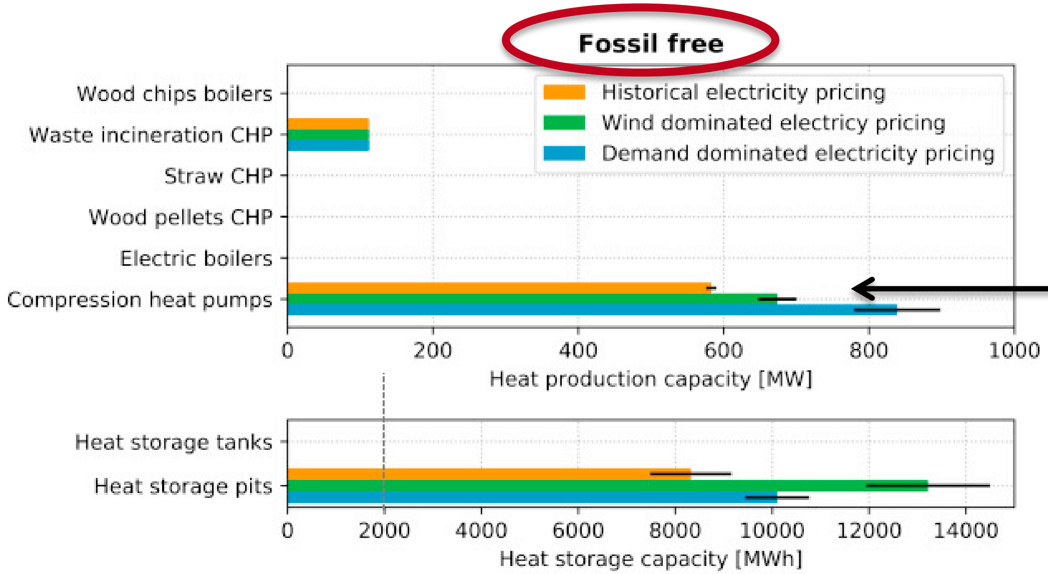
Electricity price scenarios: Results



Results for the *fossil free scenarios* are more robust.

Robust recommendations: For the choices of technologies considered here, the fossil free scenario shows *a* ***single cluster*** of ***very similar*** optimal systems.

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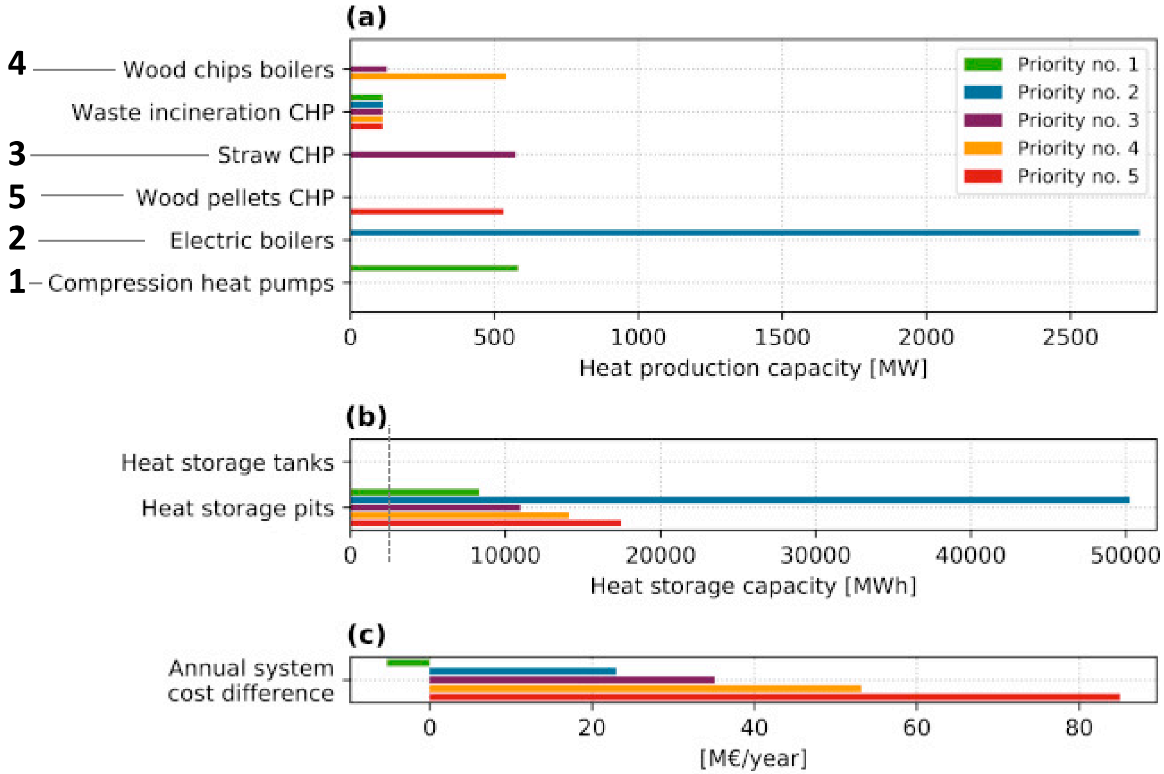
Optimized fossil free alternatives



The generating technologies are *forced* out of the optimization in order of *popularity*.

The cost reference is the cost of *re-building* the system as of 2015.

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Conclusion

- Combining optimization and scenarios allows better comparison between alternatives.
- Different clusters of optimal solutions may be found with similar cost assumptions.
- Fossil free scenarios appear more robust.

Read more: https://doi.org/10.1016/j.energy.2018.10.044

Analysis techniques for the transformation of buildings and distribution networks to 4th generation district heating (4GDH)

ECTS credits:
5 ECTS

Course parameters:
Language: English
Level of course: PhD course
Time of year: 21-25 January 2019
No. of contact hours/hours in total incl. preparation, assignment(s) or the like: 45 contact hours / 135 hours total.
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