Cost sensitivity of optimal sector-coupled district heating production systems

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Motivation

**Simulation:**
- **Good:** Explore ideas where the cost is: Highly uncertain or different for different people.
- **Bad:** Operator bias is very likely to occur and scenarios are hard to compare.

**Optimization:**
- **Good:** Consistent method to pick a complex solution. Well defined cost function.
- **Bad:** Operator bias is very likely to occur costs can difficult to include in a meaningful way.

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

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Agenda

• Use the Aarhus case to discuss sensitivity analysis.

Cost sensitivity of optimal sector-coupled district heating production systems

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Abstract

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 boiler, 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 storages more than doubles, if fossil fuels are not

Read more: https://doi.org/10.1016/j.energy.2018.10.044
The case keeps the model realistic.

**MODEL DESIGN & VALIDATION**

Aarhus
- 3 TWh heat
- 1.5 TWh power
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

\[
\begin{align*}
\min & \quad \sum_{u \in \text{prod. units}} c_u^{\text{el}} P_u^{\text{el}} + c_u^{\text{heat}} P_u^{\text{heat}} \\
& + \sum_{s \in \text{storages}} c_s^{\text{stor}} H_s \\
& + \sum_{t=1}^{N} \Delta t \left( \sum_{u \in \text{prod. units}} o_u^{\text{el}} P_{u,t}^{\text{el}} + o_u^{\text{heat}} P_{u,t}^{\text{heat}} \\
& \quad + \sum_{s \in \text{storages}} \left( o_s^{\text{disp}} h_{s,t} + o_s^{\text{upt}} f_{s,t} \right) \right)
\end{align*}
\]

Operational costs
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
How different are the *optimal* solutions?

**SCENARIOS AND RESULTS**

- Technology costs
  - Fuel prices
  - Capital costs

- The surrounding energy system
  - Electricity market prices
Multivariate cost variations

(a) Boiler technologies (fuel based).

<table>
<thead>
<tr>
<th>Boiler type</th>
<th>Fuel cost [(\epsilon/MWh_{fuel})]</th>
<th>CapEx [(\epsilon/MW_{heat})]</th>
<th>OpEx_{fixed} [(\epsilon/MW_{heat}/yr)]</th>
<th>OpEx_{variable} [(\epsilon/MW_{heat})]</th>
<th>Lifetime [yr]</th>
<th>(\eta^{boiler}) [-]</th>
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</thead>
<tbody>
<tr>
<td>Wood chips</td>
<td>24</td>
<td>0.8</td>
<td>0</td>
<td>5.4</td>
<td>20</td>
<td>1.08</td>
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<tr>
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<td>2</td>
<td>1.1</td>
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<td>1.03</td>
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<td>2</td>
<td>0.26</td>
<td>25</td>
<td>0.94</td>
</tr>
</tbody>
</table>

All fuel and investment costs

Latin hyper cube sampling

Gaussian probability distribution

- Technology costs
  - Fuel prices
  - Capital costs

G.B. Andresen, November – 2018
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200x scenario: All technologies

Fossil fuels included

Three different clusters of optimal solutions.
200x scenario: Fossil free

A single cluster of optimal solutions.
Electricity price scenarios

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.
Similar optimal technologies are identified for all price scenarios.

Optimal capacities are quite uncertain.

Error bars represent 1 standard deviation.
Electricity price scenarios: Results

Robust recommendations: For the choices of technologies considered here, the fossil free scenario shows a single cluster of very similar optimal systems.
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.
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.
Capacity limits: 25

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