Long-term production planning in large district heating systems

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The challenge

![Graph showing hourly heat load with months on the x-axis and heat load on the y-axis. The graph distinguishes between winter and summer production.](image)

- **Winter production**
- **Summer production**

Legend:
- 2015 heat load
- 2016 heat load
- Cost cross-over
Economic potential

- Potential annual savings: 4.5 – 7.6 million €
- 5% of annual operational production costs
- Average year: 6.3 million €
Two stages

1) Perfect knowledge analysis

2) Practical decision rules
Merit order of production units

- The Aarhus production system

Winter production

- Municipal waste
- Straw CHP
- Oil etc.
- Wood pellets CHP

Summer production

- Municipal waste
- Straw CHP
- Oil etc.
Weather-based modeling

- 38 years of weather data
- 38 years of heat load
- Production plan with CHP
- Production cost with CHP
- Production plan without CHP
- Production cost without CHP
- Cost vs shutdown/start-up date
Cost vs shutdown date

- **Relative seasonal cost**
- **CHP shutdown date**
  - Total cost, spring
  - Optimal shutdown
  - 90% saved
  - 80% saved
  - Shutdown unsafe

- **Relative seasonal cost**
- **CHP start-up date**
  - Total cost, fail
  - Optimal start-up
  - 90% saved
  - 80% saved
  - Start-up too late
Optimal spring shutdown

- Optimal shutdown
- 80% saved
- 90% saved
- Shutdown unsafe

CHP shutdown date


Dates: Mar 18, Mar 25, Apr 01, Apr 08, Apr 15, Apr 22, Apr 29, May 06, May 13, May 20, May 27, Jun 03, Jun 10, Jun 17, Jun 24, Jul 01, Jul 08
Optimal fall start-up
Decision rules for shutdown/start-up

- Fixed date rule
- Load based rule
- Load based rule with 15 day forecast

Trade-off
Planning horizon vs performance
Load based decision rule

- Shut down the plant in the first time step $t$ in which:

$$\frac{1}{T_1} \sum_{t'=t-T_1}^{t} P_{t'} \leq \tau_1$$

$$\frac{1}{T_2} \sum_{t'=t-T_2}^{t} P_{t'} \leq \tau_2$$

$$t \geq t_{\text{fixed}} - T_{\text{anchor}}$$

$P_{t'}$: Heat load in hour $t'$$$
\tau_1, \tau_2$: Thresholds

$T_1, T_2$: Smoothing time scales

$T_{\text{anchor}}$: Anchoring time scale

$t_{\text{fixed}}$: Fixed date rule shutdown
Measuring performance of the rules

- Scoring: Production cost vs reference scenario

- Model selection
  - 7-fold cross-validation on 35 years
  - Tuning of parameters e.g. $T_1$, $T_2$
  - Least squares training determines $\tau_1, \tau_2$

- Cross-validation reduces risk of overfitting
Performance of the rules

- 100% score: Full saving potential achieved

**Spring: CHP shutdown**

- Fixed date rule
- Load based rule
- Load based rule w. forecast

**Fall: CHP start-up**

- Scores for different years and rules are displayed.
Conclusions

- Large economic potential: 6.3 million € annually

- Most of the potential can be realized using:
  - Fixed date rule: 90.7%
  - Load based rule: 95.8%
  - Load based rule with forecasts: 96.5%

- Accuracy comes at the cost of shorter planning horizons
Thank you for listening!

Further reading: