Joint Optimization under Uncertainty for Heat & Power Systems (WP7)

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Me, me, me!

- Italian, in Denmark since 2006
- Background: Electrical/Automation Engineer
- PhD awarded in 2013 at DTU Compute
  - Managing renewables in power systems
  - Optimization/modeling uncertainty
- Recently PostDoc within CITIES
- Research focus:
  - Stochastic programming
  - Robust optimization
  - Decision rules
  - Hierarchical optimization
  - ...
  - Applications in energy markets/systems
Why Considering Heat & Power Systems Jointly?

Motivation:

• Integration of **renewables** in Denmark will involve both sectors (wind, biofuels, etc.)

• Heat and power systems are **interdependent**

• Heat system can provide **flexibility** to integrate renewables

Challenges:

• Need for joint decision-making tools to exploit these synergies

• Optimization models ought to account for **uncertainty** (demand, prices, etc.)

• System **dynamics** (multistage)
Optimization under Uncertainty Framework

**FIRST STAGE**
Day-ahead decisions $x$
- Unit on/off status (binary)
- Production plan
- Market trade

**SECOND STAGE**
Real-time decisions $y(\delta)$
- Actual production
Second-stage decisions are functions of uncertainty realization

Uncertainty $\delta$ realizes
- Heat demand
- Power price
- Wind power production

Day-ahead cost
(profit changed in sign)

Projection of real-time cost
(profit changed in sign)

Minimize:

$$
\begin{align*}
& c_x^T x + \text{Exp}_\delta \{ c_y^T y(\delta) \} \\
\text{subject to:} & \\
& A_x x + A_y y(\delta) \geq b(\delta), \quad \forall \delta 
\end{align*}
$$

The planning must guarantee feasible real-time operation under a number of plausible realizations of the uncertain parameters.
Stochastic Programming vs Robust Optimization

Stochastic Programming
- scenario-based
- day-ahead, real-time

Robust Optimization
- uncertainty set
- $\delta_1$, $\delta_2$

Recourse approximation
- discretization
- $y \rightarrow \delta$

- piecewise-linear
- $y \rightarrow \delta$
Robust Management of Heat & Power Systems

- Optimize management of heat and power systems:
  - planning
  - trading
  - operation
- Want to account for uncertainty:
  - heat demand
  - power prices
- We aim at a conservative solution: heat supply guaranteed for the most extreme realization of heat demand
Peculiarities of the model

- We cast the problem as a robust optimization model
- Piecewise-linear decision rules approximate optimal recourse: recourse is affine function of the uncertainty
- We model trading in multiple commodity markets
- Uncertainty enters optimization model via simple descriptions (support set, mean, correlation, etc.)
Optimal Trading for Wind Farms and CHP Plants  
(Anna Hellmers’ M.Sc. project)

- Analysis of joint trading strategies for wind/CHP plants in the balancing market
- Assessment of how the heat system can help balance the deviations of wind power
- Real-world data from existing plants
- State-of-the-art forecasting models for uncertainty (heat demand, power prices, wind)
Probabilistic Forecasting and Optimization for CHP Systems
(Maria Nielsen’s M.Sc. Project)

- Assessment of societal value of electrical boilers and heat pumps
- Real-world data from the Greater Copenhagen area including taxes and subsidies
- Model based on stochastic programming to account for uncertain heat demand
Ongoing and Future Work

- Production of three peer-reviewed articles (ongoing)
  - *Commitment and Dispatch of Heat and Power Units via Affinely Adjustable Robust Optimization* (Zugno, Morales, Madsen)
  - *Assessing the Role of Heat Pumps and Electrical Boilers in the Danish Heat and Power Systems* (Nielsen, Zugno, Morales, Madsen)
  - *Portfolio Operation Strategies for Wind Farms and CHP Plants in a Dual-Price Balancing Market* (Hellmers, Zugno, Morales, Skajaa)

- Realistic case-study assessing the potential of RO vs current management strategies for heat and power systems (ongoing)

- Refinement of RO model
  - More realistic modeling of the trading process
  - More sophisticated modeling of the uncertainty