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Decision Making Models and Support Systems

Background

Denmark is one of the most energy-efficient countries in the world. The interaction between the different energy systems maintains a sustainable energy sector that fulfills the long-term energy policy targets. In this work, we mainly distinct between the district heating and the power systems. On the one hand, the **district heating system** provides a reliable heating supply to consumers, on the other hand, the **power system** supply electricity to houses and industries.

The large scale integration of renewable sources into the Danish energy system involves both the power and the heat sector through expansion of wind and bio-fuels. Heat and power systems are nowadays independently operated. However, the presence of CHP units, heat pumps, electric boilers can provide the flexibility needed to integrate larger shares of fluctuating sources of power. In consequence, joint decision-making tools to operate heat and power systems together must be developed to exploit these synergies.

Technologies

The integration of these two systems is achieved due to the coordination of different production technologies.

- **Combined heat and power plants (CHP):** They can produce heat and power at the same time.
- **Fuel boilers (FB):** They can produce heat by burning any type of fuel.
- **Electric boilers (EB):** They can produce heat by the use of electricity.
- **Heat pump (HP):** Large units that can produce heat by consuming electricity.
- **Solar collector (SC):** They produce heat by solar concentration.
- **Thermal storage (TS):** Used as heat storage for all technologies, improving the efficiency of the system.

It is important to distinct between **flexible** units that allow an immediate and adjustable production and **non-flexible** units that they need to be programmed in advance or their production is not adjustable.

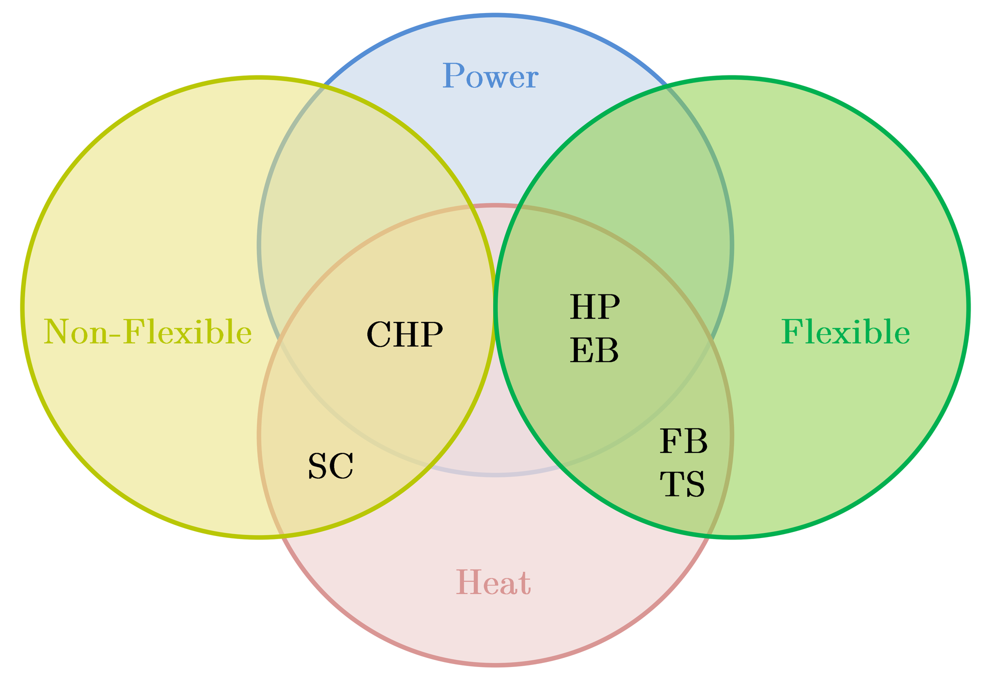
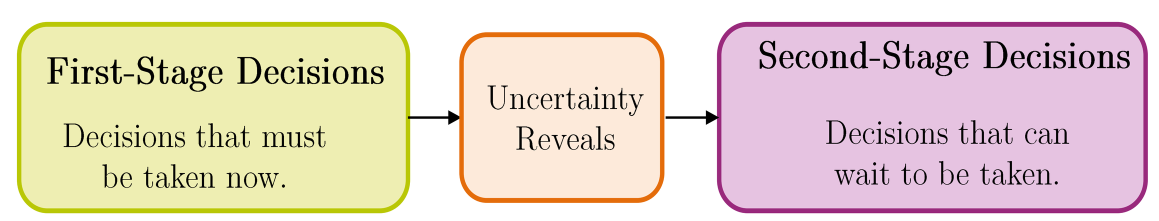


Figure 1: Heat production technologies.

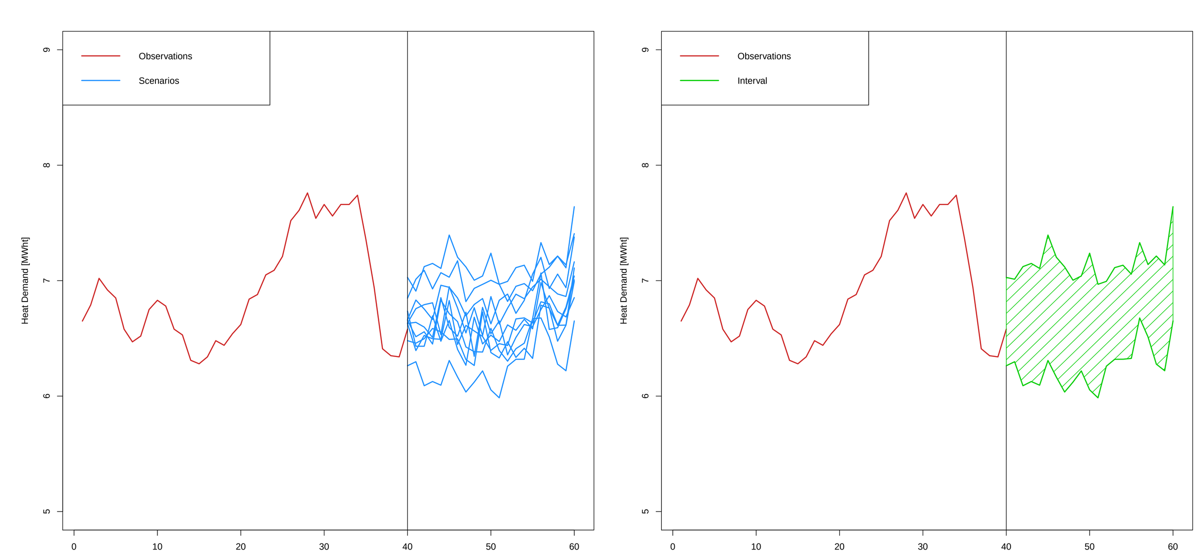
Methodology

Heat and power systems are largely uncertain (due to demands, production and prices). We solve this problem using **decision-making under uncertainty.**



$$x = \begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix} \qquad \delta = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \dots \\ \delta_m \end{bmatrix} \text{ or } [\underline{\delta}, \overline{\delta}] \qquad y(\delta) = \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_m \end{bmatrix} \text{ or } y(\delta) = A\delta + B$$

We account for stochasticity through **stochastic programming** and **robust optimization.**



(a) Uncertainties represented as scenarios. (b) Uncertainty represented as intervals.

Figure 2: Uncertainty characterization.

Stochastic Programming

Uncertainty is modeled using **scenarios** that are interpreted as discrete values of the uncertainty as in Figure 2a. The recourse or second-stage variables are represented as discrete values as well.

$$\begin{aligned} \underset{x, y_\delta}{\text{minimize}} \quad & c^T x + \mathbb{E}[d^T y_\delta] \\ \text{s.t.} \quad & A_x x + A_y y_\delta \leq b \quad \forall \delta \in \{1, ..., m\} \end{aligned}$$

Robust Optimization

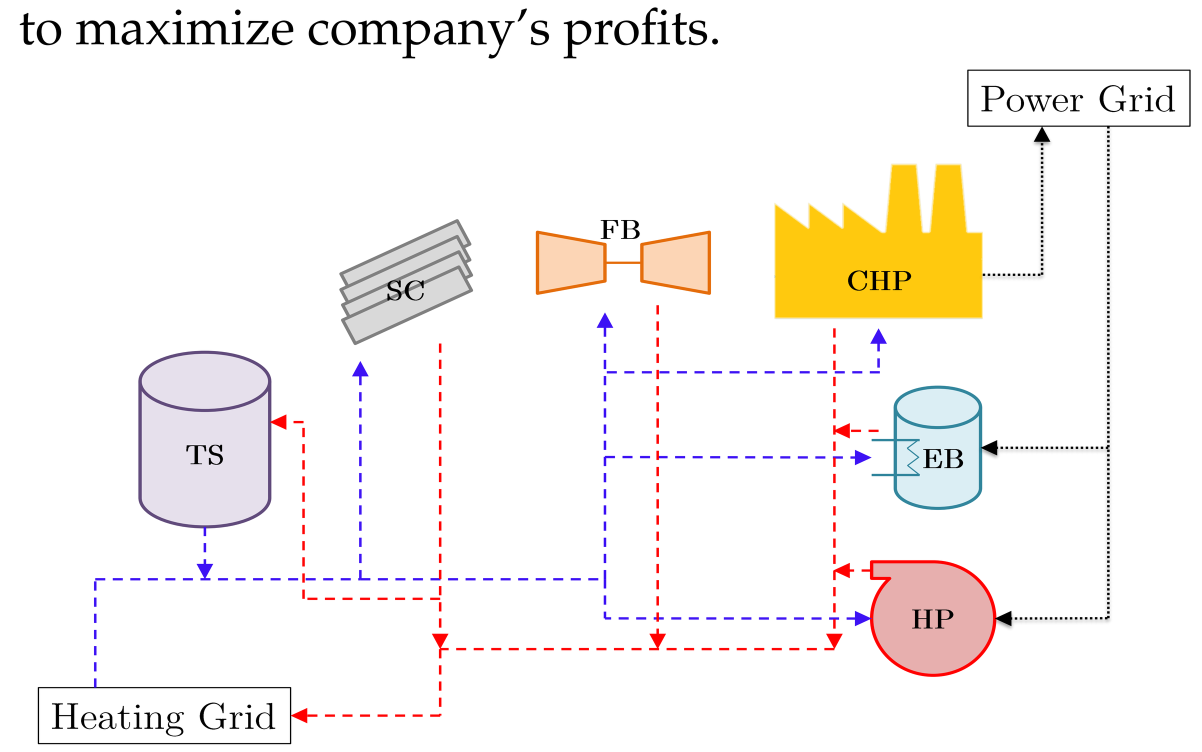
Uncertainty is modeled as a dynamic interval. The uncertainty is continuous and not discrete as in Figure 2b, therefore the second-stage variables or recourse must take values within such interval. This interval is represented as a line and this names **linear decision rule**.

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & c^T x + \beta \\ \text{s.t.} \quad & \underset{\delta}{\text{maximize}} \{d^T A \delta\} \leq \beta - d^T B \\ & \underset{\delta}{\text{maximize}} \{A_y A \delta\} \leq b - A_x x - A_y B \end{aligned}$$

Robust optimization is applied to obtain a solution that (i) is feasible for all possible realizations of the uncertainty or (ii) is optimal for the worst-case realization of the uncertainty.

Case Example

It consists of a district heating company operating different types of units to supply the heat demand. The aim is to optimize the scheduling of the units in order to maximize company's profits.



The decision framework is characterized as follows:

- **First-stage Decisions:** The decision we must provide here and now is the amount of power and the bidding price we want to trade in the day-ahead electricity market.
- **Uncertainties:** The uncertainties that affect our first stage decisions are the amount of heat demanded from the system and the heat production from the solar collectors. These can be modeled as scenarios or intervals.
- **Second-stage Decisions:** These are the actual heat production of the flexible units in the system.

Previous and future case studies

Work has been done in CITIES work-package 7 regarding the integration of heat and power systems using decision-making under uncertainty.

Previous:

- Optimizing Electricity Market Trading for Wind Turbines and CHPs (MSc Thesis and journal paper).
- Probabilistic Forecasting and Optimization for CHP Systems (MSc Thesis and journal paper).
- Robust Management of Heat & Power Systems via Decision Rules (Journal Paper).

On-going:

- Decision-making under uncertainty to support the planning of biomass supply for CHP producers.

Future:

- Optimization under uncertainty of heat and power production in district heating systems.

Team Members and further information

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