Characterising Industrial Sites' Flexibility with Reservoir Models

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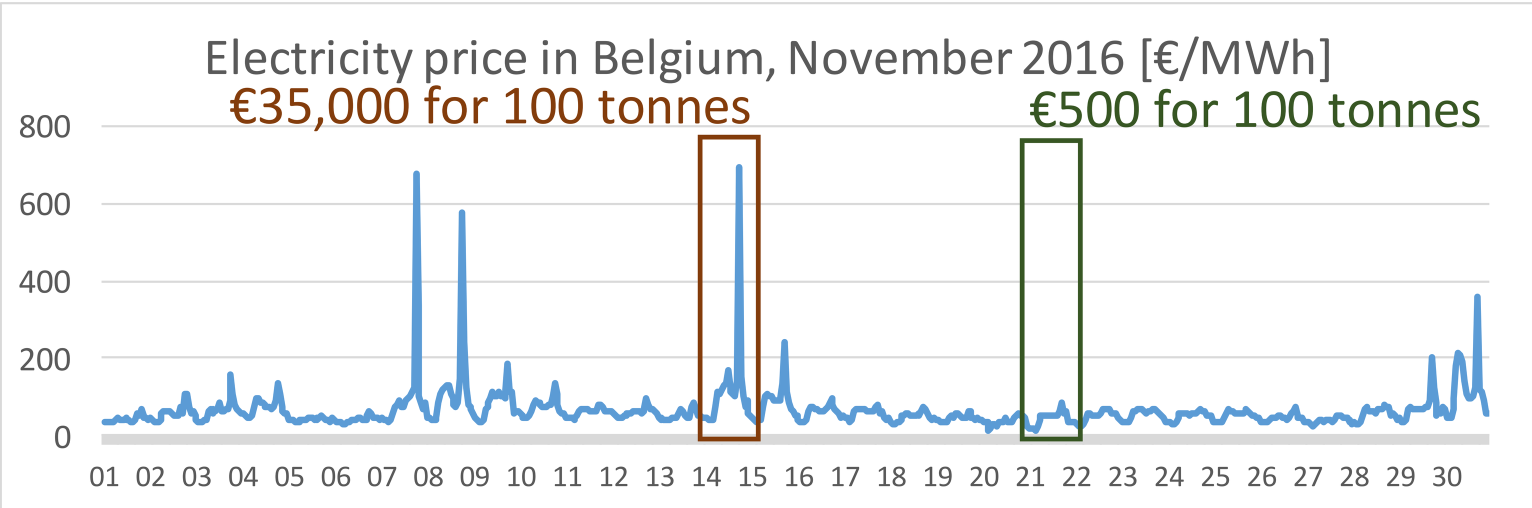
Why flexibility?

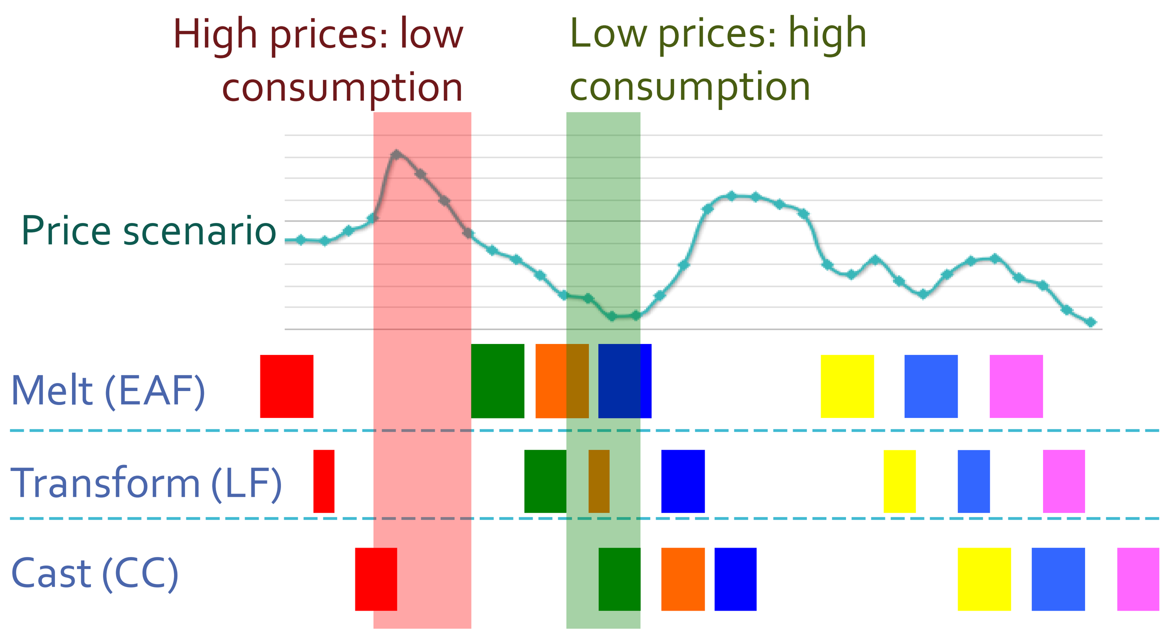
- Large electricity **price variations** are more and more frequent, mostly due to renewables
- Significant **impact on production costs**!
- Response? Flexible production planning!



Steel mill: roughly 50 MWh/100 tonnes

Flexibility how-to

- Order book not too tight: operators can **schedule production** to lower costs (load shifting)
- Next step: **plant open only when electricity is cheap**



What is needed to exploit industrial flexibility?

A model of the plant and of each of its processes → For each process, a model that links consumption and production. Based on **existing** industrial data (hard to perform experiments) → Hence **reservoir** models!

Reservoir building blocks

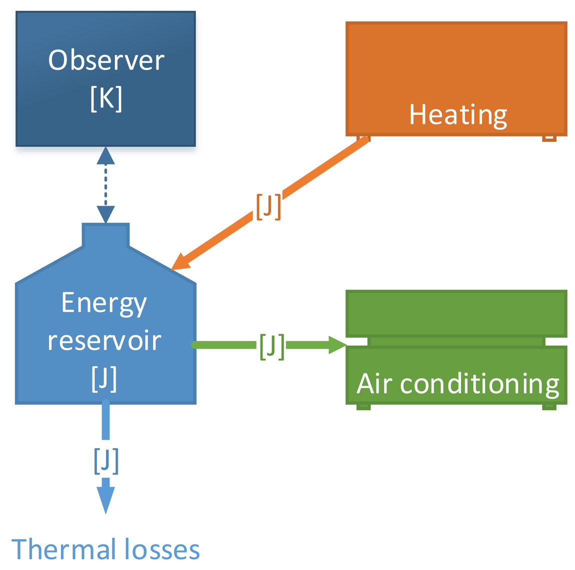
- Most industrial processes **store** multiple quantities: an oven stores metal and energy, e.g.; hence **reservoirs**
- Reservoir models are thus **physically-based**, which helps extrapolation outside known operating ranges
- Several kinds of reservoirs:
  - **Standard** reservoir: $s_{t+1} = s_t + in_t - out_t$
  - **Decaying** reservoir: $s_{t+1} = s_t + in_t - out_t - decay_t$
  - **Observer** reservoir: $s_t = f(u_t, v_t\ldots)$
  - **Processes**: link flows and consumptions

Toy example: HVAC

Corresponding MI(L)P model?

$$\min \sum_t \left[\text{price}_t^e \left(\mathbf{elec}_t^h + \mathbf{elec}_t^a \right) + \text{price}_t^g \left(\mathbf{gas}_t^h + \mathbf{gas}_t^a \right) \right]$$

$$\begin{aligned} \text{s.t. } & \mathbf{energy}_{t+1} = \mathbf{energy}_t + \mathbf{heating}_t - \mathbf{ac}_t - \mathbf{losses}_t \\ & \mathbf{temperature}_t = C_p \times m \times \mathbf{energy}_t \\ & T_{\min} \leq \mathbf{temperature}_t \leq T_{\max} \\ & \mathbf{heating}_t = f\left(\mathbf{elec}_t^h, \mathbf{gas}_t^h\right) \\ & \mathbf{ac}_t = g\left(\mathbf{elec}_t^a, \mathbf{gas}_t^a\right) \\ & \mathbf{losses}_t = k \times \left(\mathbf{temperature}_t - T_t^{out}\right) \end{aligned}$$



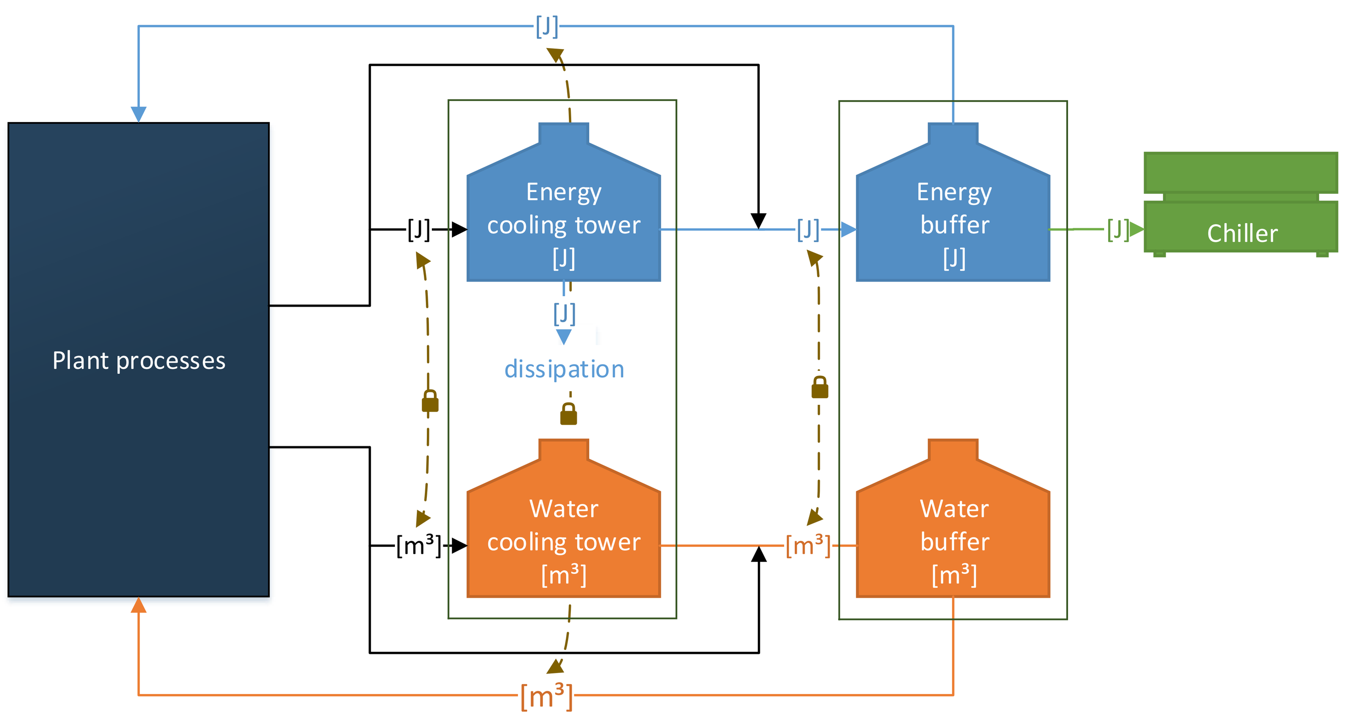
Fitting the parameters?

$$\min \sum_s \left[\left(\mathbf{elec}_{t,s}^h + \mathbf{elec}_{t,s}^a - \text{elec}_t^s \right)^2 + \left(\mathbf{gas}_{t,s}^h + \mathbf{gas}_{t,s}^a - \text{gas}_t^s \right)^2 \right]$$

$$\text{s.t. reservoir model for sample } s$$

Test case: industrial cooling

- Test case: a polypropylene-film plant, with many **heat-producing** barely-flexible processes
- **Cooling**: both a cooling tower and a chiller
- **2 reservoirs per machine**: volume of water, heat
- **Subtlety**: flows of water and heat are **coupled** with temperature
  - Nonlinear, nonconvex strict **equalities**



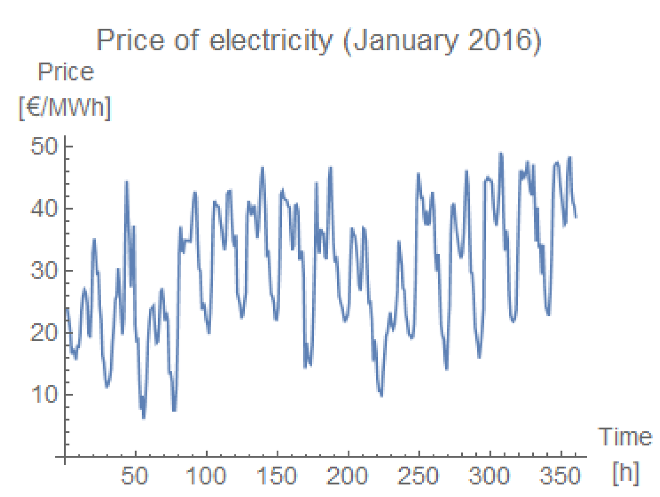
Model choice for the equalities

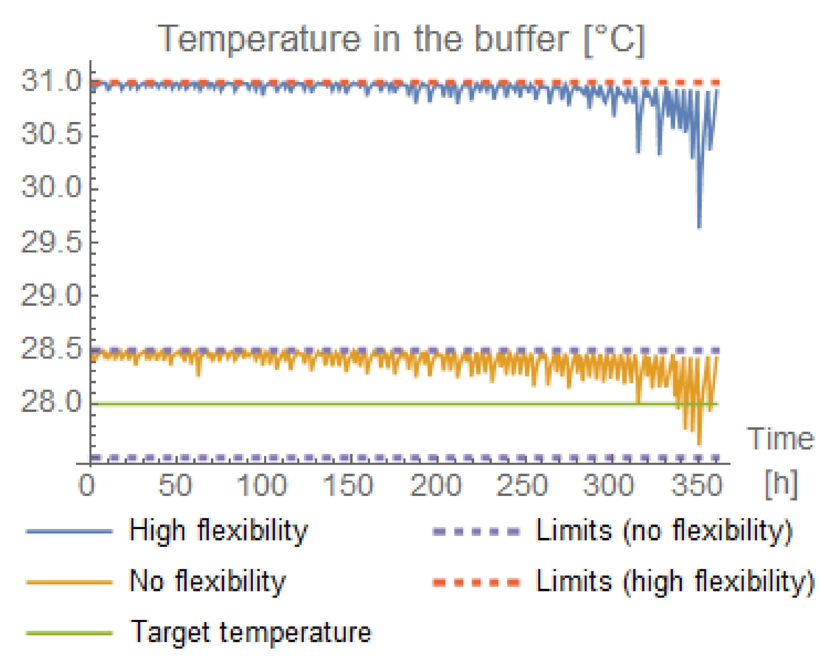
- Need a rather high precision for temperature
- Either MILP (with discretisation) or MINLP (nonconvex)
- MINLP with Couenne: can solve an 8h-instance in less than 5 min
- MILP with Gurobi/CPLEX: impossible (20 levels for discretisation)
- Still, must use a rolling-horizon algorithm due to problem size

Results

- Compare two scenarios:
  - **Without flexibility**: water returned to the plant within strict temperature bounds
  - **With flexibility**: looser bounds (water hotter when electricity is expensive, cooler when electricity is cheaper)
- Without surprise: flexibility lowers the energy bill
- For two weeks:
  - **Without flexibility**: €123,570
  - **With flexibility**: €93,909

  → Gain: **24%!**





- Temperature close to maximum allowed
- Follows price scenario: price and temperature drop simultaneously