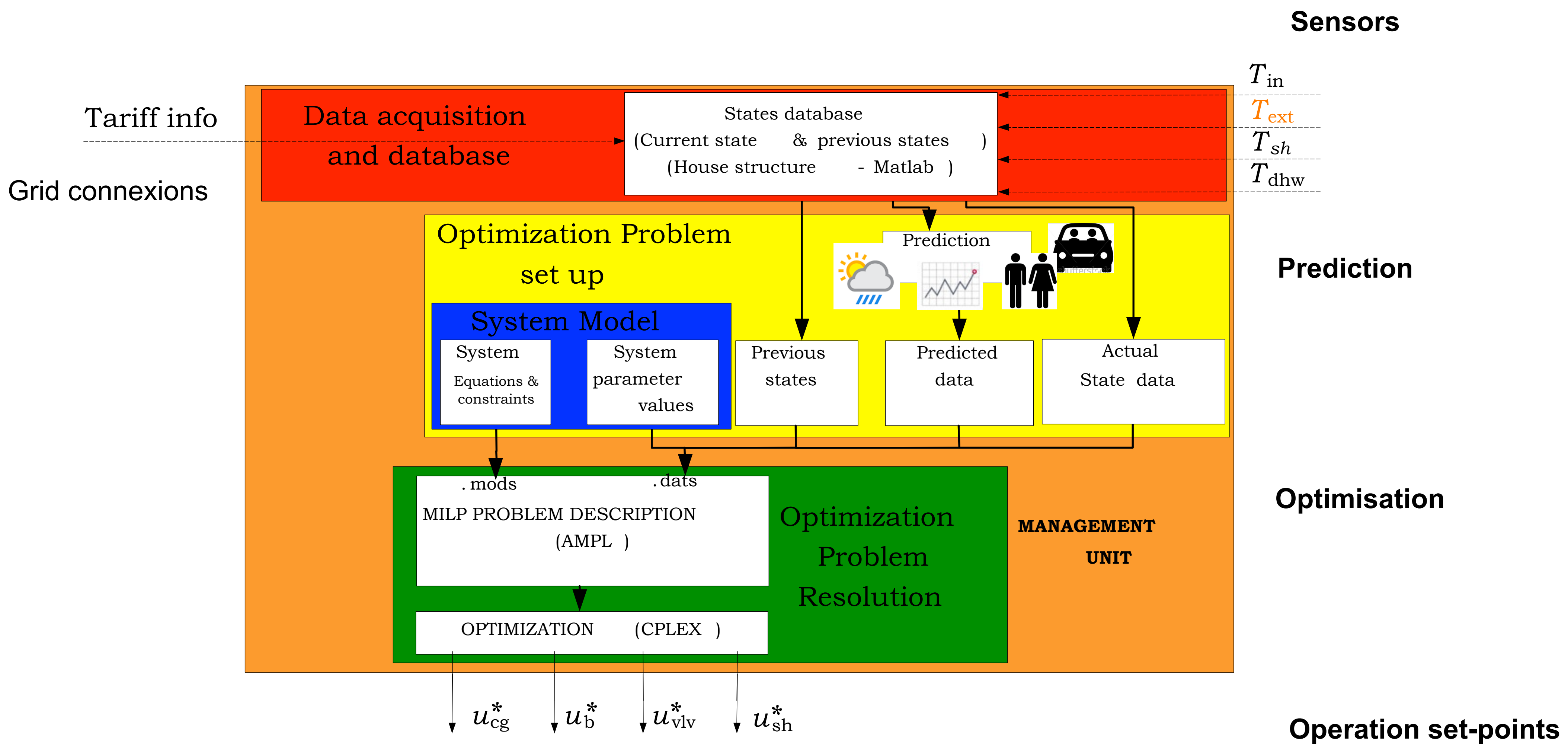
Implementing the model predictive control

Model predictive control



Collazos et al., Computers and Chemical Eng. 2009

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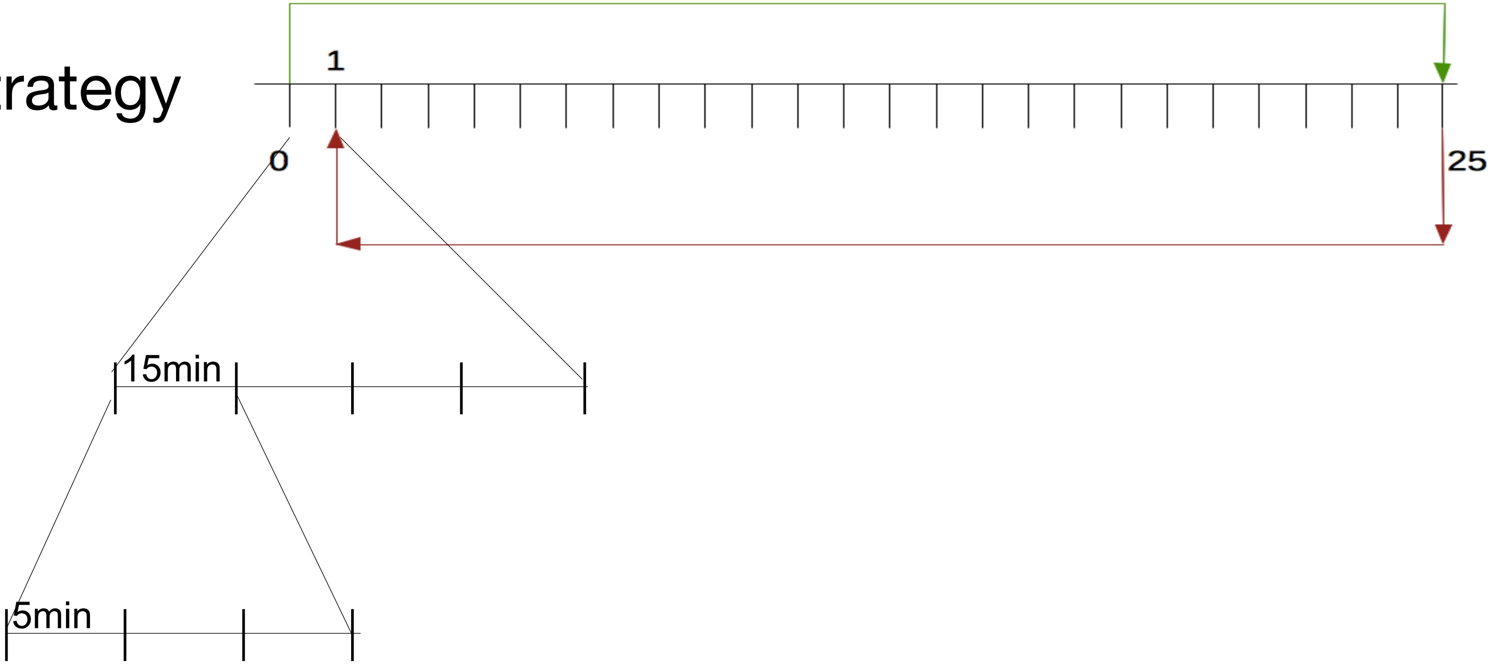
Electrical grid : Integrating different time scales

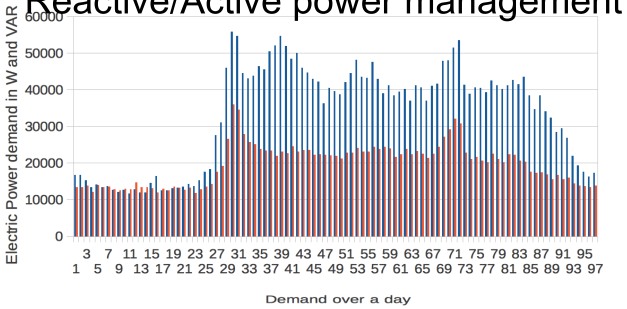
Defines t+1h target state, with a 25 hours horizon and cyclic contraints



- Heating time scale (1h) => strategy
- Electricity (15min)
  => Mean power corrections
- Electricity (second)
  => Reactive/Active power
  => Frequency control

depends on
- Power electronics
- Equipments (AC/DC)

Reactive/Active power management



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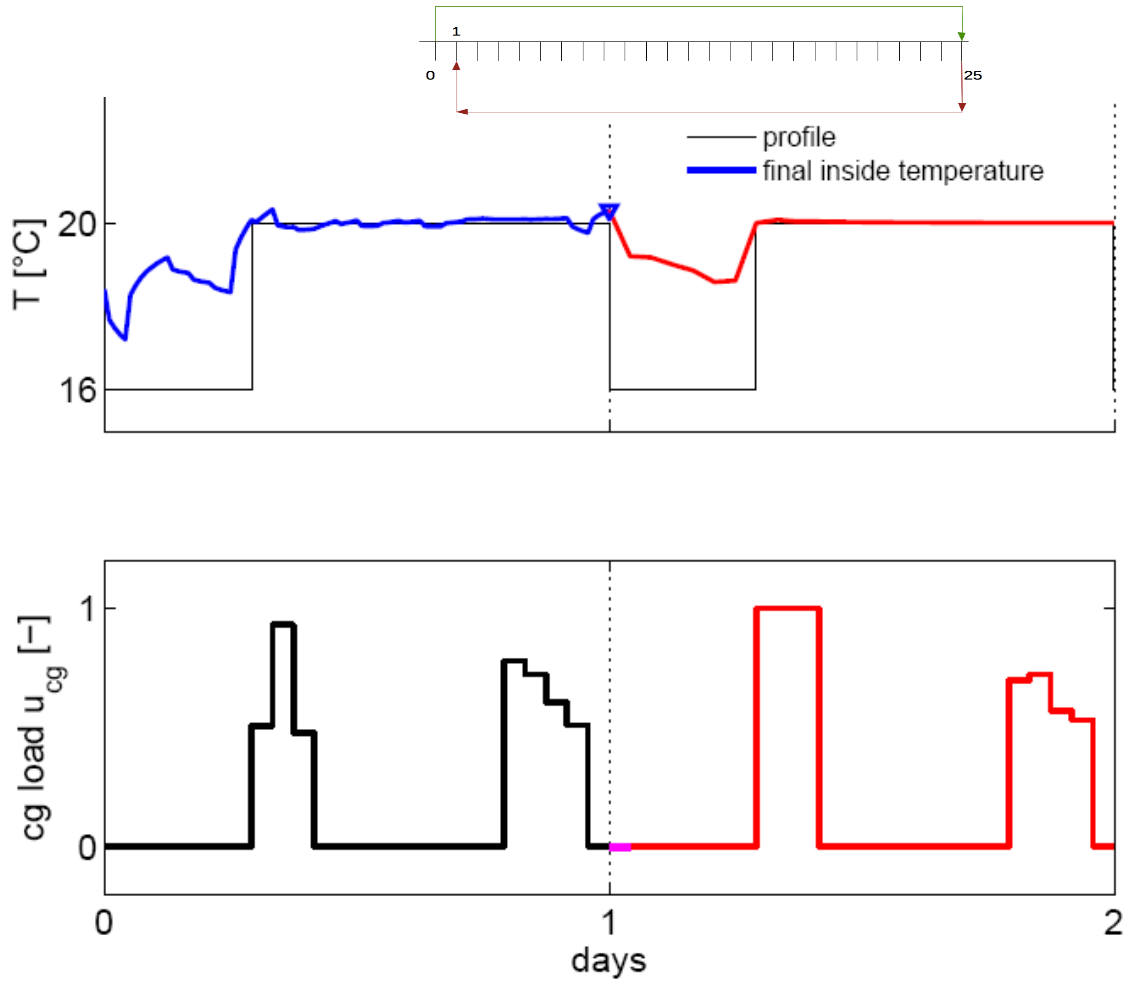
Predictive Controller

- **Predictive Control Algorithm : Moving horizon**
  - **hour 1 : set-point control + 24 h Cyclic : strategy**



Adaptation of the cost function

$$J_{\text{obj}} = J_1 + w \cdot \sum_t T_{\text{inf}}(t)$$

$$w = 10^6$$

subject to:

$$T_{\text{inf}}(t) \geq 0$$

$$T_{\text{inf}}(t) \geq T_{\text{profile}}(t) - T_{\text{inside}}(t)$$

Comfort temperature ➡ energy service !

where:

Electricity : Import and export !

$$J1 = \sum_t^{Time} \left(\left\{\sum_n^{Nodes} \sum_u^{Units(n)} (\dot{m}^+_{r(u),n} c_{r(u),n})\right\} + \dot{E}^+(t)c^+_{el}(t) - \dot{E}^-(t)c^-_{el}(t)\right)\Delta t$$

$$\dot{E}^+(t) - \dot{E}^-(t) + \left(\sum_n^{Nodes} \sum_u^{Units(n)} \dot{E}^+_{u,n}(t) - \dot{E}^-_{u,n}(t)\right) - \sum_n^{Nodes} \dot{E}_{c,n} = 0$$

$$\dot{E}^+(t) + \left(\sum_n^{Nodes} \sum_u^{Units(n)} \dot{E}^+_{u,n}(t) - \dot{E}^-_{u,n}(t)\right) - \sum_n^{Nodes} \dot{E}_{c,n} \geq 0$$

$$\sum_u^{Units(n)} \dot{m}^+_{r(u),n} \eta_{th_{u,n}} - \sum_s^{Storage(n)} \dot{Q}^+_{s,n} - \dot{Q}_{c,n} = 0 \quad \forall n \in Nodes$$

Predictive Controller

- **Structure of the predictive controller**
  - **start-up/ shut-down** $cg_{\mathrm{on}}(t) \in \{0,1\}$

$$\dot{Q}_{cg}^{min} \cdot cg_{on}(t) \leq \dot{Q}_{cg}(t) \leq \dot{Q}_{cg}^{max} \cdot cg_{on}(t) + cg_{start-up}(t) \cdot \eta_{cg,th}^{start-up} \cdot \dot{Q}_{cg,gas}^{max}$$

  - **Non linear efficiency**

$$\begin{aligned}\dot{E}_{cg}(t) =& cg_{on} \cdot \dot{E}_{cg}^{min} + cg_{start-up}(t) \cdot \eta_{cg,el}^{start-up} \cdot \dot{Q}_{cg,gas}^{max} \\ &+ cg_{pw} \left[m_{el,1} \left(\dot{Q}_{cg}(t) - \dot{Q}_{cg}^{min} \right) + \dot{E}_{cg}^{min} \right] \\ &+ (1 - cg_{pw}(t)) \left[m_{el,2} \left(\dot{Q}_{cg}(t) - \dot{Q}_{cg,pw} \right) + m_{el,1} \left(\dot{Q}_{cg,pw} - \dot{Q}_{cg}^{min} \right) \right]\end{aligned}$$

- **Prediction of**
  - the energy requirements (dhw, heat, electricty),
  - the free gains (e.g. solar, from appliances, inhabitants, …), and
  - the electricity market conditions
  - Control set-point

Micro grid integration mechanisms

Market opportunities

$$J1 = \sum_{t}^{Time} \left(\left\{ \sum_{n}^{Nodes} \sum_{u}^{Units(n)} (\dot{m}^{+}_{r(u),n} c_{r(u),n}) \right\} + \dot{E}^{+}(t) c^{+}_{el}(t) - \dot{E}^{-}(t) c^{-}_{el}(t) \right) \Delta t$$

$$\dot{E}^{+}(t) - \dot{E}^{-}(t) + \left(\sum_{n}^{Nodes} \sum_{u}^{Units(n)} \dot{E}^{+}_{u,n}(t) - \dot{E}^{-}_{u,n}(t) \right) - \sum_{n}^{Nodes} \dot{E}_{c,n} = 0$$

Market Commitment

Penalty on deviations

$$J1 = \sum_{t}^{Time} \left(\left\{ \sum_{n}^{Nodes} \sum_{u}^{Units(n)} (\dot{m}^{+}_{r(u),n} c_{r(u),n}) \right\} + \dot{E}^{+}(t) c^{+}_{el}(t) - \dot{E}^{-}(t) c^{-}_{el}(t) + P \Delta \dot{E}^{+}(t) \right) \Delta t$$

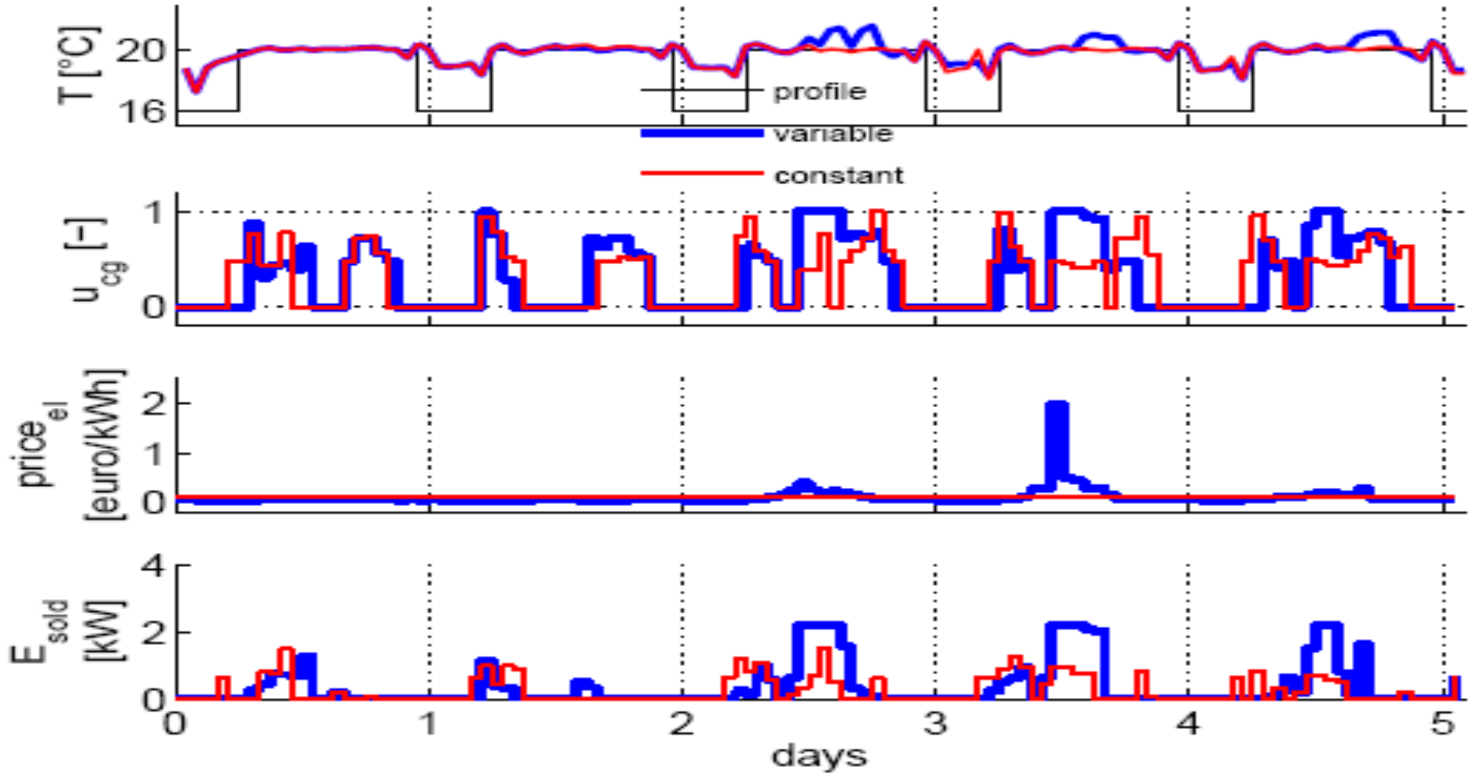
$$\dot{E}^{+}(t) - \dot{E}^{-}(t) + \left(\sum_{n}^{Nodes} \sum_{u}^{Units(n)} \dot{E}^{+}_{u,n}(t) - \dot{E}^{-}_{u,n}(t) \right) - \sum_{n}^{Nodes} \dot{E}_{c,n} = 0$$

$$\left| \dot{E}^{+}(t) - \dot{E}^{+}_{committed}(t) \right| = \Delta \dot{E}^{+}(t)$$

Day ahead commitment calculated at a reference time by the controler using the MPC algorithm

Response to the market price variation

- **Electricity cost is changing**



	$cost_{op}$[€]	Potential gain [€]
Reference day	36.00	0.0
Regular day	30.55	5.45
High cost days	21.14	14.86

Same heat
EEX market price
40% heating cost reduction

Optimal strategic operation of processes

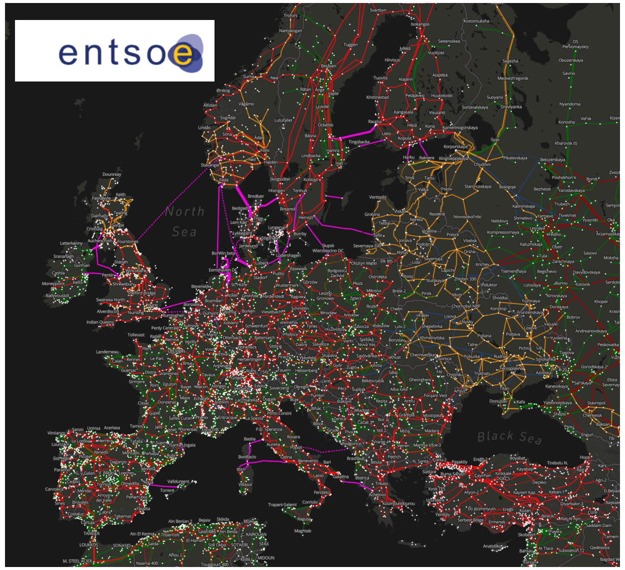
Application example: **batch process** in Switzerland

- 5 production lines
- 2 final products (A and B)
- 2 raw materials and 5 intermediates

Subject to constraints of final products delivery quantities and dates

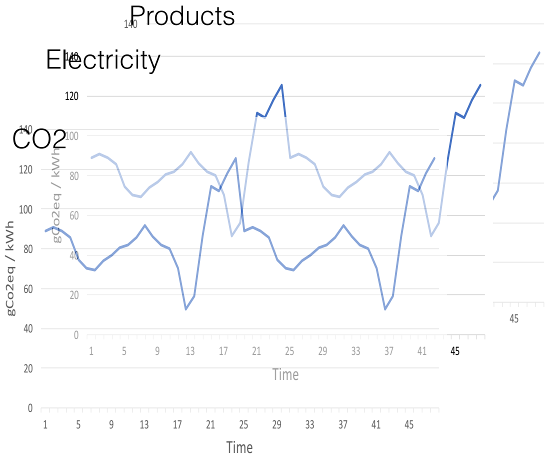
CO2 emission forecast for next two days based on the ENTSOE data base

Transparent data base

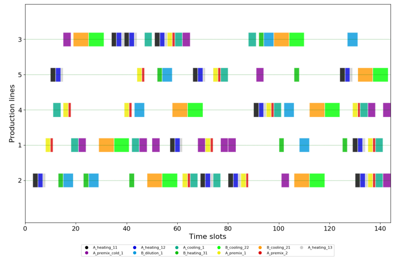


https://www.entsoe.eu/data/map/

Predictions



Model based Optimal scheduling



Life cycle impact Data

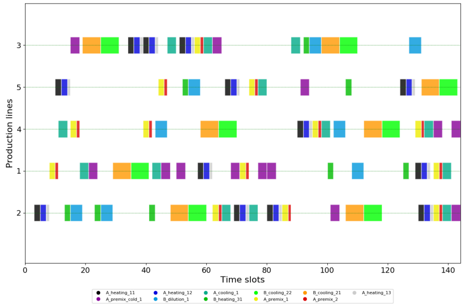
Process Data

optimal predictive strategic operation scheduling

Status of inventory+ equipment

Market predictions

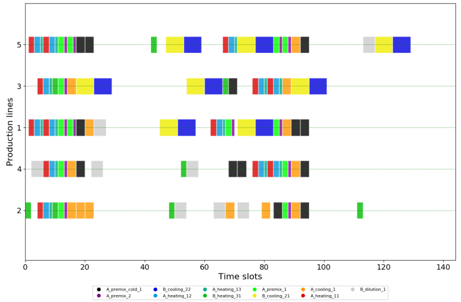
50 hours ahead prediction



Minimisation of the energy consumption

Utility market

Electricity consumption [MWh]	Operating cost [EUR]	CO2 emissions [kgCO2eq]
32.3	745.5	958.5

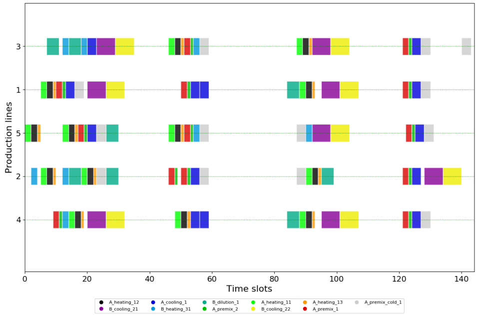


Minimisation of the operating cost

Electricity market

Electricity consumption [MWh]	Operating cost [EUR]	CO2 emissions [kgCO2eq]
32.3	640.1	870.2

-14.2 %



Minimisation of CO2 equivalent emissions

CO2 market

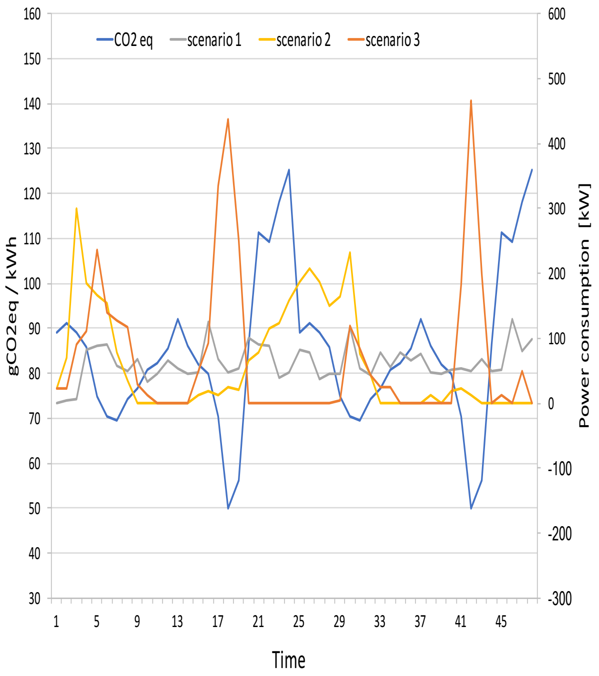
Electricity consumption [kWh]	Operating cost [EUR]	CO2 emissions [gCO2eq]
32.3	747.5	690.0

-27.9 %

Blockchain

Strategic planning

different presence on the grid



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