A case study on medium-term hydropower scheduling with sales of capacity

Master's thesis findings

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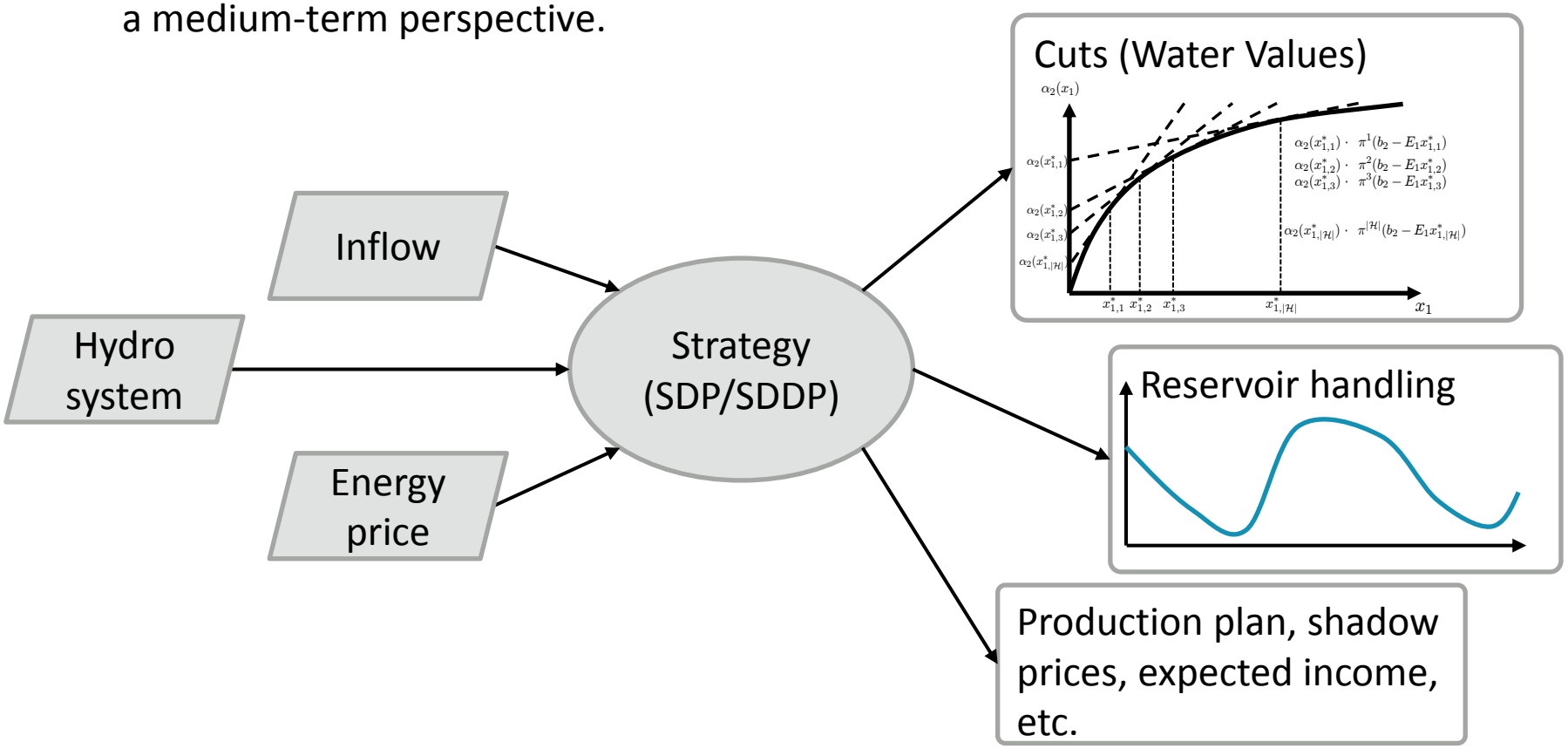
Problem Description

- Overall goal

  Optimize production scheduling with uncertainty in energy prices and inflow with a medium-term perspective.



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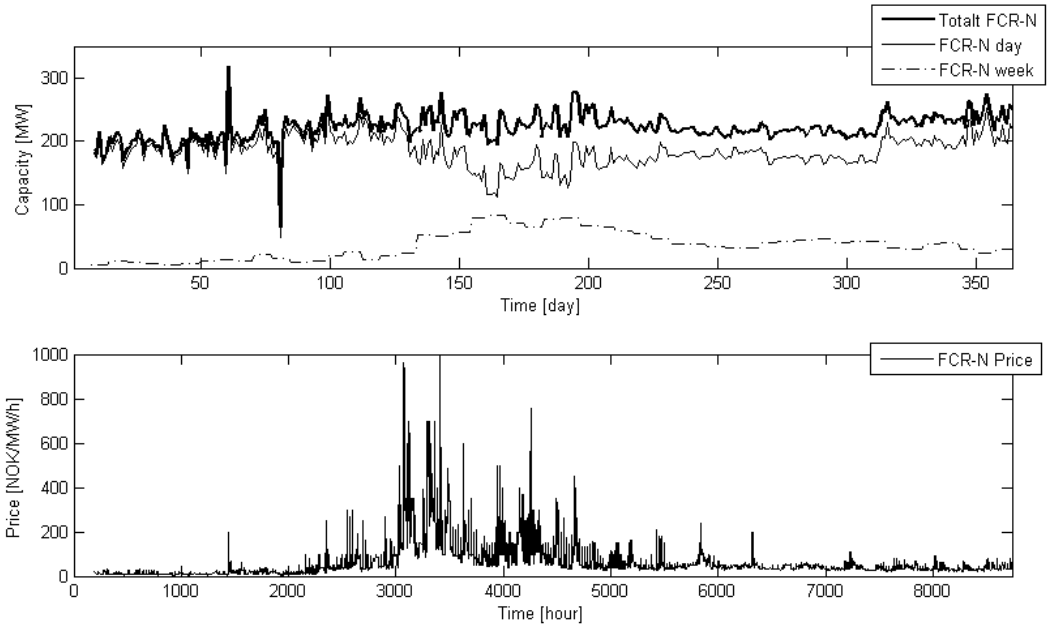
Problem Description

•Overall goal(NEW)

Optimize production scheduling with uncertainty in energy price, inflow and capacity price (Deterministic) with a medium-term perspective.



FCR-N (primary frequency reserve) market price and volume in 2013.

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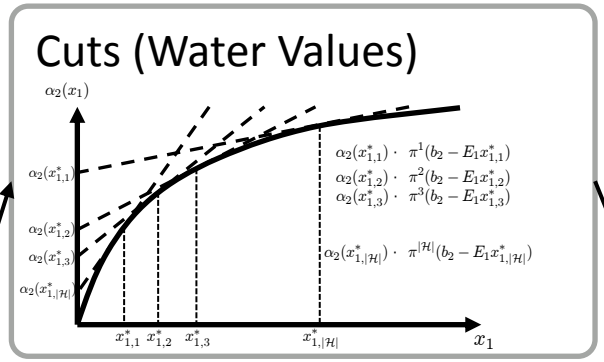
Problem Description



Inflow

Hydro system

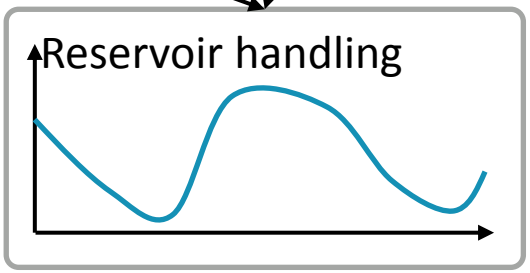
Energy price

Capacity price

Strategy

Simulator (MIP Based)

Production plan, shadow prices, expected income, etc.



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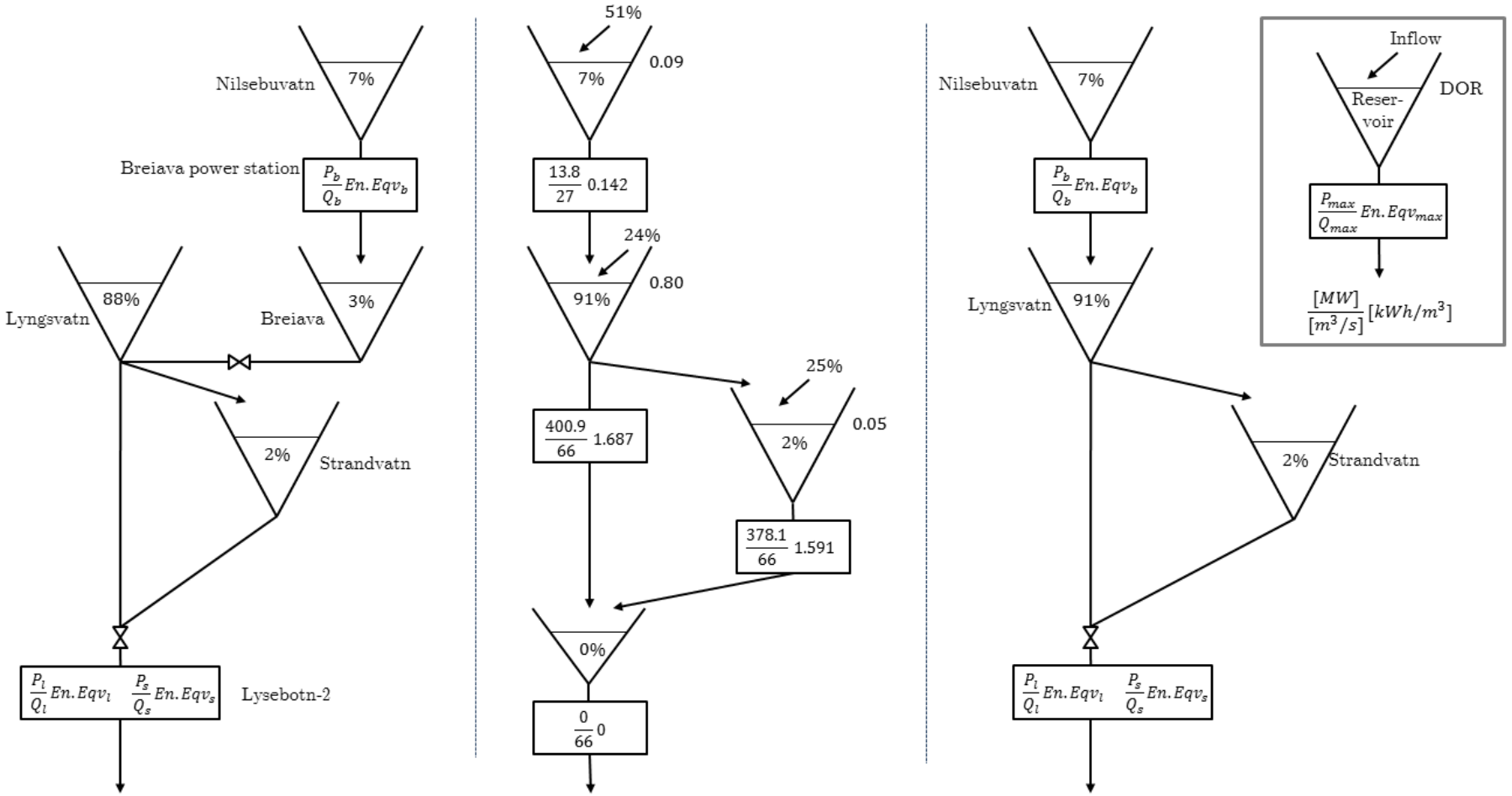
Models Overview

- Strategy (SDDP)
  - Objective: Profit maximization
  - s.t.
  - Reservoir balance
  - Energy balance
  - Spinning capacity
  - Start-up cost (linear)
  - Hydraulic coupling

- Simulator (MIP)
  - Objective: Profit maximization
  - s.t.
  - Reservoir balance
  - Energy balance
  - Spinning capacity
  - Start-up cost (binary)
  - Hydraulic coupling
  - Minimum production level
  - Power-discharge function

Hydro System



Physical system

Strategy system

Simulator system

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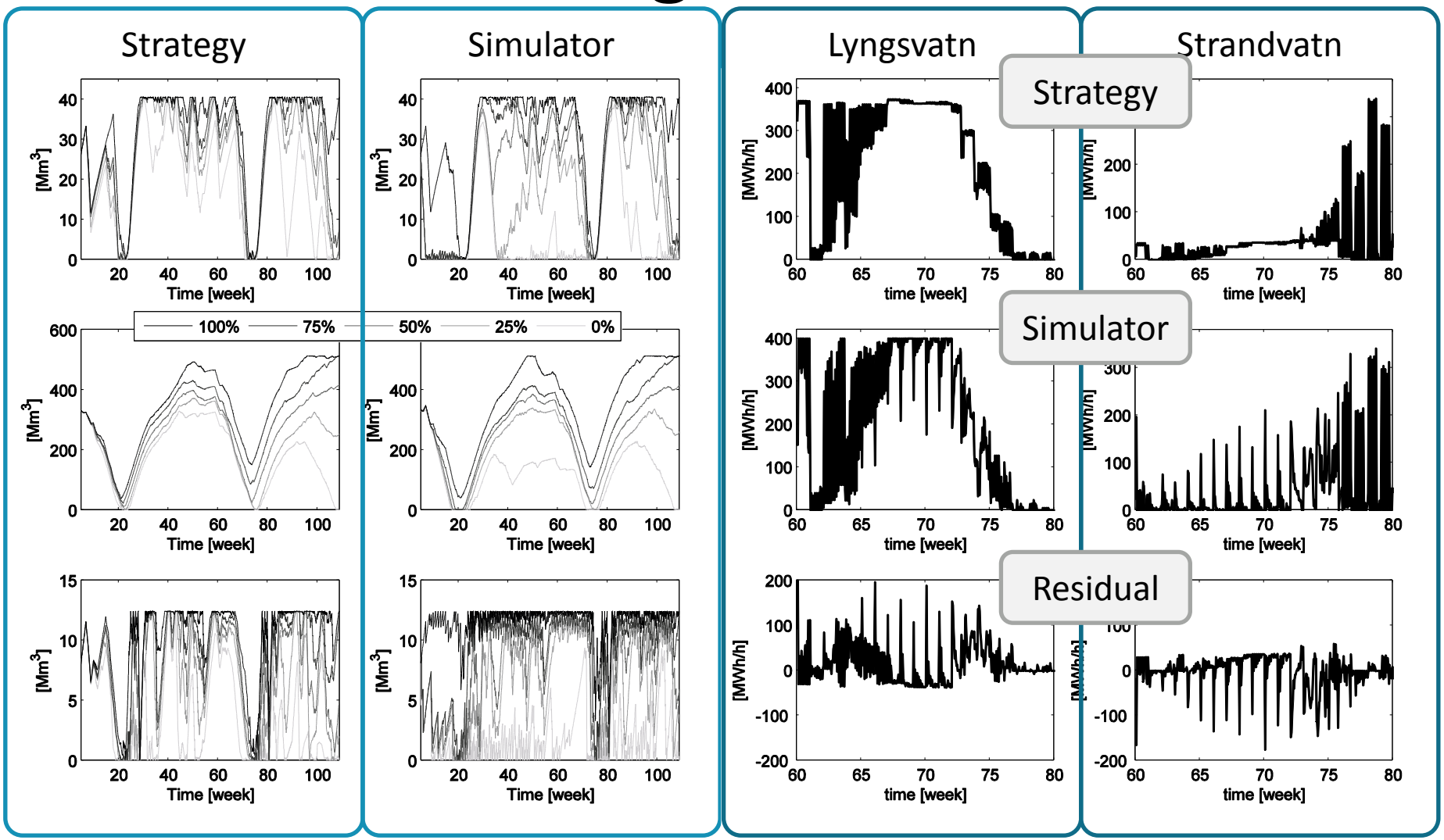
Reservoir Handling and Production



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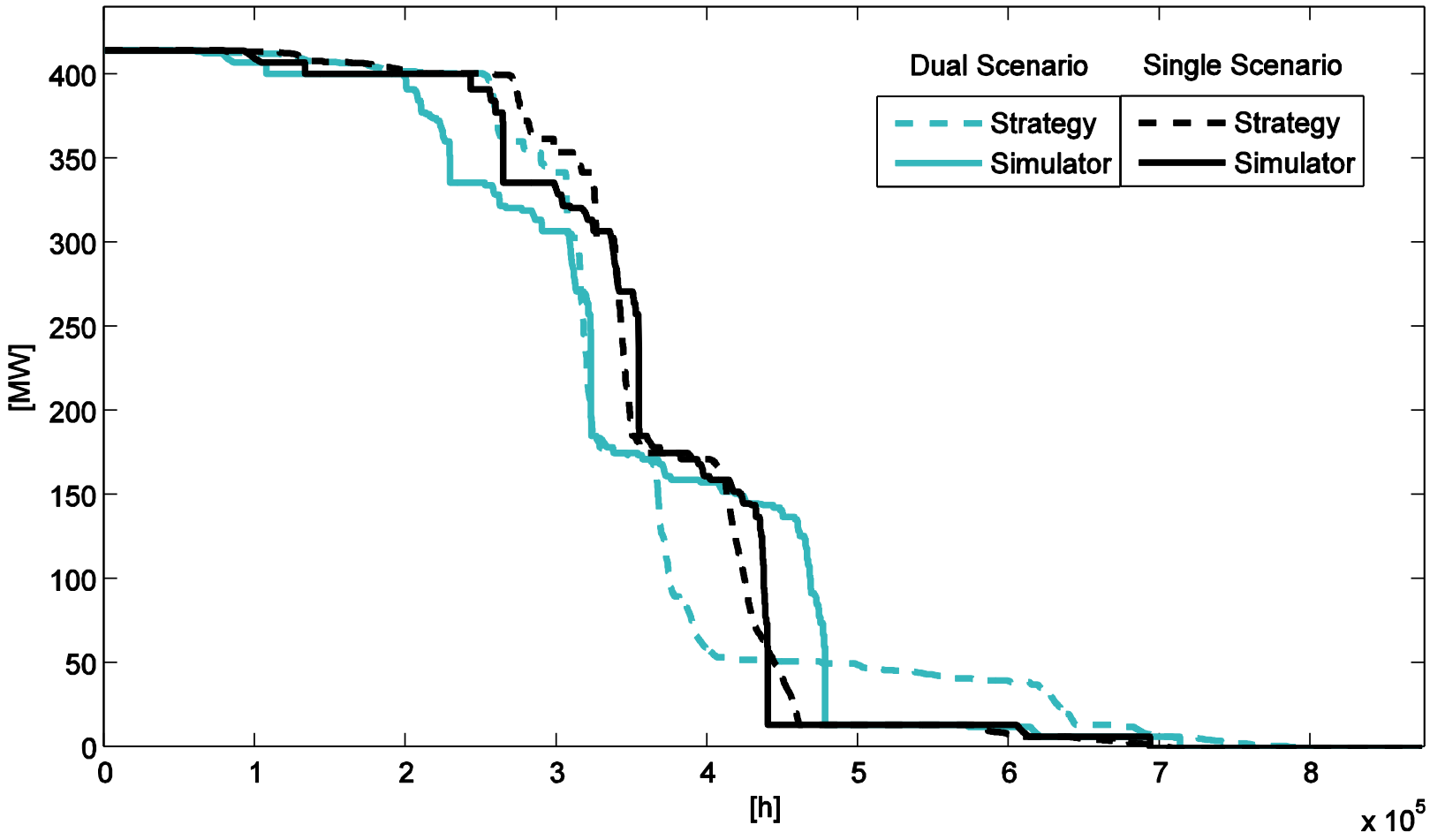
Duration Curve



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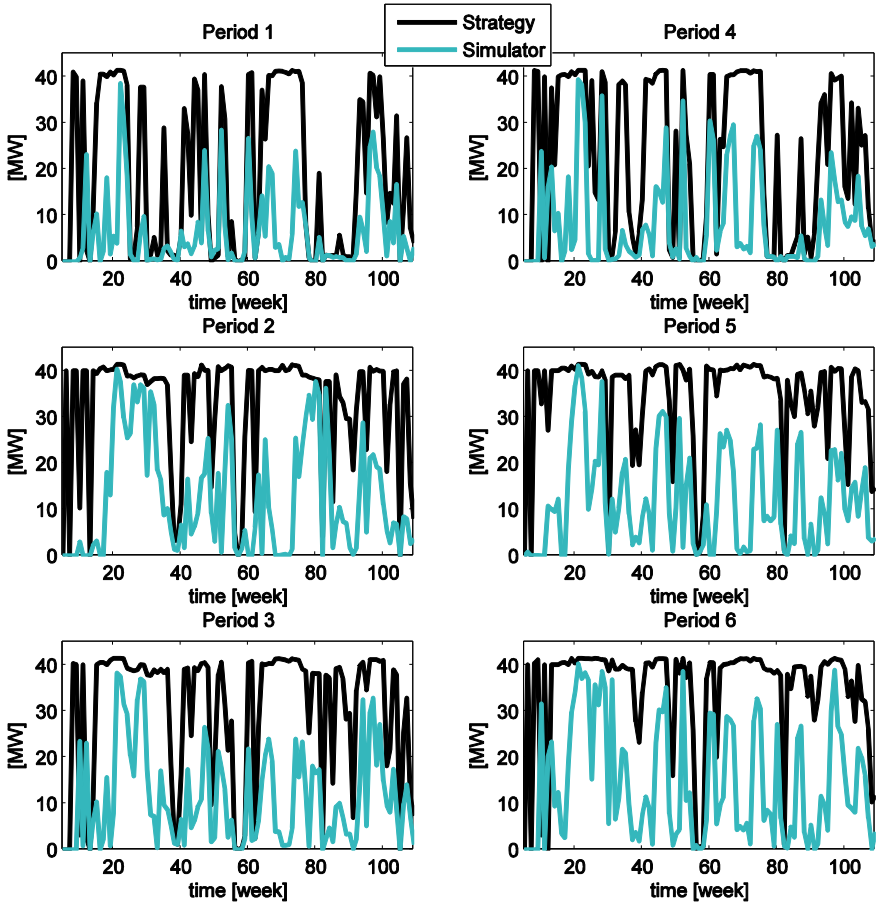
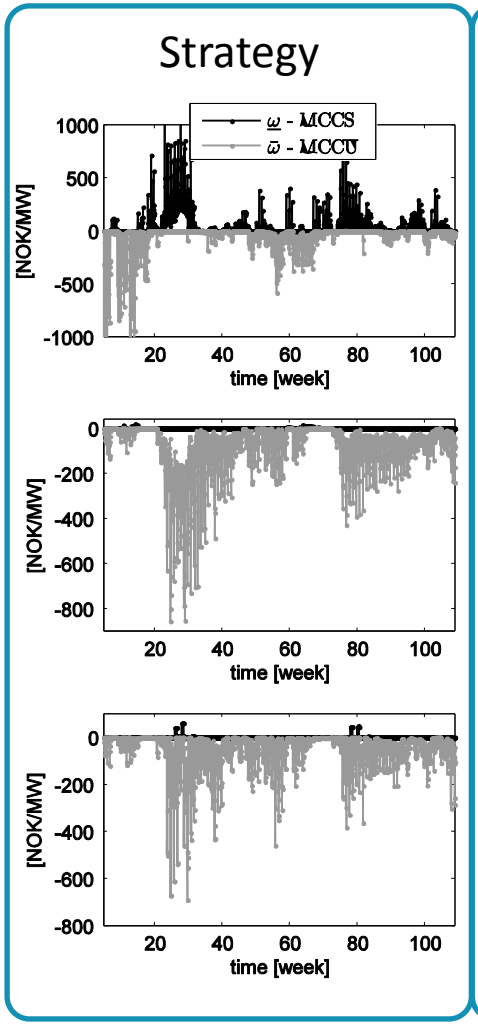
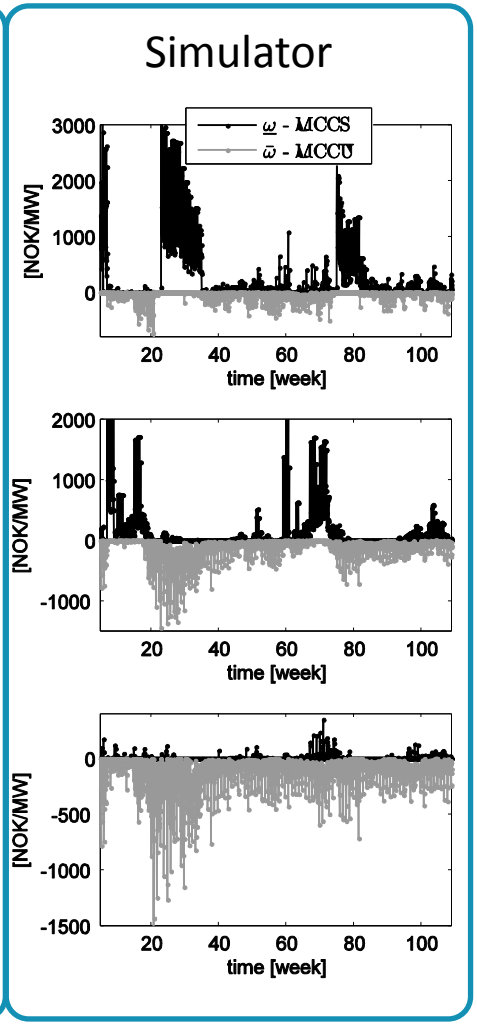
Sales of Capacity







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Conclusions

- 52% Reduction of profit from sales of capacity from the Strategy to the Simulator Model
- Gain for dual market scheduling off 2.6% (Strategy) and 1.3% (Simulator)

- Further work:
  - Parallelization
  - SDP benchmark
  - Capacity market modelling

Thank you!

Questions?

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Strategy

$$\hat{\alpha}_t(v_t, z_t) = \text{Max } \{\Sigma_{w\in\mathcal{W}} W_w \big[\lambda^B_{t,c} p^B_{t,c} + \lambda^S_t \kappa^S_{t,w}(e^S_{t,w} - \tau e^P_{t,w}) - \Sigma_{m\in\mathcal{M}}(\lambda^T \varpi_{t,w,m} + \lambda^F s_{t,w,m})\big] - \Sigma_{w\in\mathcal{W}}\Sigma_{m\in\mathcal{M}}\lambda^U \delta_{t,w,m} + \hat{\alpha}_{t+1}\} \quad (3.39)$$

s.t.

$$v_{t,w,m} + W_w\big[\Sigma_{i\in\mathcal{S}_m} q_{t,w,m,i} + s_{t,w,m} + b_{t,w,m} + \varpi_{t,w,m} - \Sigma_{k\in\Omega_m}(s_{t,w,k} + b_{t,w,k} + q_{t,w,k})\big] = v_{t-1,1,m} + \frac{W_w}{\Sigma_{w\in\mathcal{W}} W_w} I_{t,m}(z_{t-1,m}), \quad \forall w \in \mathcal{W},\ \forall m \in \mathcal{M} \quad (3.40)$$

$$\Sigma_{m\in\mathcal{M}}\Sigma_{i\in\mathcal{S}_m}\eta_{w,m,i} q_{t,w,m,i} - e^S_{t,w} - e^P_{t,w} = 0,\ \forall w \in \mathcal{W} \quad (3.41)$$

$$\Sigma_{i\in\mathcal{S}_m}\gamma_{w,m,i} q_{t,w,m,i} - p^B_{t,w,m} \geq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.42)$$

$$\Sigma_{i\in\mathcal{S}_m}\gamma_{w,m,i} q_{t,w,m,i} + p^B_{t,w,m} \leq P^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.43)$$

$$\Sigma_{m\in\mathcal{M}} p^B_{t,w,m} - p^{B_{tot}}_{t,c} = 0, \qquad \forall w \in \mathcal{W}, \forall c \in \mathcal{C} \quad (3.44)$$

$$\Sigma_{k\in\mathcal{B}_m} p^B_{t,w,m} \leq \text{ Max } \{\, P^{B_{max}}_k : \forall k \in \mathcal{B}_m \,\}, \qquad \forall w \in \mathcal{W} \quad (3.45)$$

$$\Sigma_{i\in\mathcal{S}_m} q_{t,w,m,i} - Q^{min}_m u^L_{t,w,m} - (Q^{max}_m - Q^{min}_m) u^H_{t,w,m} = 0,\ \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.46)$$

$$u^L_{t,w,m} - u^H_{t,w,m} \geq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.47)$$

$$u^L_{t,w,m} - u^L_{t,w-1,m} - \delta_{t,w,m} = 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.48)$$

$$0 \leq u_{L,t,w,m} \leq 1, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.49)$$

$$0 \leq u_{H,t,w,m} \leq 1, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.50)$$

$$0 \leq q_{t,w,m,i} \leq Q^{max}_{m,i}, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M}, \forall i \in \mathcal{S} \quad (3.51)$$

$$0 \leq b_{t,w,m} \leq B^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.52)$$

$$0 \leq v_{t,w,m} \leq V^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.53)$$

$$0 \leq p^B_{t,w,m} \leq P^{B_{max}}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.54)$$

$$\hat{\alpha_{t+1}} \leq \alpha^*_{t+1} + \Sigma_{m\in M}\pi^j_{t+1,m}(v_{t,m} - v^*_{t,m}) + \Sigma_{m\in M}\mu^j_{t+1,m}(z_{t,m} - z^*_{t,m}) + \Sigma_{m\in\mathcal{M}}\phi^j_{t+1,m}(u^L_{t,w,m} - u^{*L}_{t,w,m}), \quad \forall j \in \mathcal{H}_m, w = |W| \quad (3.55)$$

Simulator

$$\hat{\alpha}_t(v_t, z_t) = \text{Max } \{\Sigma_{w\in\mathcal{W}} W_w \big[\lambda^S_t \kappa^S_{t,w}(e^S_{t,w} - \tau e^P_{t,w}) + \Sigma_{c\in\mathcal{C}}\lambda^B_{t,c} p^B_{t,c,m} - \Sigma_{w\in\mathcal{W}}\Sigma_{m\in\mathcal{M}}\lambda^U \delta_{t,w,m} + \Sigma_{m\in\mathcal{M}}(\lambda^T \varpi_{t,w,m} + \lambda^F s_{t,w,m})\big] + \hat{\alpha}_{t+1}\} \quad (3.66)$$

s.t.

$$v_{t,w,m} + W_w\big[\Sigma_{i\in\mathcal{S}_m} q_{t,w,m,i} + s_{t,w,m} + b_{t,w,m} + \varpi_{t,w,m} - \Sigma_{k\in\Omega_m}(s_{t,w,k} + b_{t,w,k} + q_{t,w,k})\big] = v_{t-1,1,m} + \frac{W_w}{\Sigma_{w\in\mathcal{W}} W_w} I_{t,m}(z_{t-1,m}), \forall w \in \mathcal{W},\ \forall m \in \mathcal{M} \quad (3.67)$$

$$W_w \Sigma_{m\in\mathcal{M}} p_{t,w,m} - e^S_{t,w} + e^P_{t,w} = 0, \qquad \forall w \in \mathcal{W} \quad (3.68)$$

$$p_{t,w,m} - p^B_{t,w,m} - P^{min}_m u_{t,w,m} \geq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.69)$$

$$p_{t,w,m} + p^B_{t,w,m} \leq P^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.70)$$

$$\Sigma_{w\in\mathcal{C}}\Sigma_{m\in\mathcal{M}} p^B_{t,w,m} - p^B_{t,c} = 0, \qquad \forall w \in \mathcal{W}, \forall c \in \mathcal{C} \quad (3.71)$$

$$u_{t,w,m} - u_{t,w-1,m} + \delta_{t,w,m} \leq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.72)$$

$$p_{t,w,m} - u_{t,w,m} P^{max}_{t,w,m} \leq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.73)$$

$$p_{t,w,m} - u_{t,w,m} P^{min}_{t,w,m} \geq 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.74)$$

$$p_{t,w,m} - \Sigma_{i\in S} p_{t,w,m,i} = 0, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.75)$$

$$p_{t,w,m,i} - \gamma_{w,m,i} q_{t,w,m,i} = 0, \qquad \forall i \in \mathcal{S}, \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.76)$$

$$\Sigma_{i\in S} x_{t,w,m,i} = 1, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.77)$$

$$Q_{w,m,i-1} x_{t,w,m,i} \leq q_{t,w,m,i} \leq Q_{w,m,i} x_{t,w,m,i}, \quad \forall i, \forall w, \forall m \quad (3.78)$$

$$\Sigma_{m\in\mathcal{B}_m} u_{t,w,m} \leq 1, \qquad \forall w \in \mathcal{W} \quad (3.79)$$

$$b_{t,w,m} + Q^{max}_{w,m} u_{t,w,m} \leq Q^{max}_{w,m}, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.80)$$

$$0 \leq b_{t,w,m} \leq B^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.81)$$

$$0 \leq v_{t,w,m} \leq V^{max}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.82)$$

$$0 \leq p^B_{t,w,m} \leq P^{B_{max}}_m, \qquad \forall w \in \mathcal{W}, \forall m \in \mathcal{M} \quad (3.83)$$

$$u_{t,w,m},\ \delta_{t,w,m} \in \{0,1\} \quad (3.84)$$

$$\hat{\alpha_{t+1}} \leq \alpha^*_{t+1} + \Sigma_{m\in\mathcal{M}}\pi^j_{t+1,m}(v_{t,w,m} - v^*_{t,w,m}) + \Sigma_{m\in\mathcal{M}}\mu^j_{t+1,m}(z_{t,w,m} - z^*_{t,w,m}) + \Sigma_{m\in\mathcal{M}}\phi^j_{t+1,m}(u_{t,w,m} - u^*_{t,w,m}), \quad \forall j \in \mathcal{H}_m, w = |W| \quad (3.85)$$

Comparing	Strategy ↦ Simulator		Single ↦ Dual	
	Single	Dual	Strategy	Simulator
Objective Value	-1.37	-3.02	0.80	-0.88
Total Generation	-0.91	-1.06	-2.60	-2.74
Energy Profit	-2.22	-2.48	-2.12	-2.39
Capacity Profit	-	-51.83	-	-
Terminal Value	2.43	2.92	14.96	15.51
Total Profit	-1.62	-2.91	2.61	1.26

	Single market		Dual market	
	Strategy	Simulator	Strategy	Simulator
Objective Value	1 416.78	1 397.30	1 428.07	1 384.97
Total Generation	3 073.31	3 045.15	2 993.28	2 961.60
Energy Profit	1 234.33	1 206.98	1 208.12	1 178.13
Capacity Profit	-	-	35.83	17.26
Terminal Value	183.34	187.79	210.77	216.92
Total Profit	1 417.67	1 394.77	1 454.72	1 412.31
CPU time	4 h 25 min	30 min	5 h 34 min	46 min