Energy Flexibility in Wastewater Treatment

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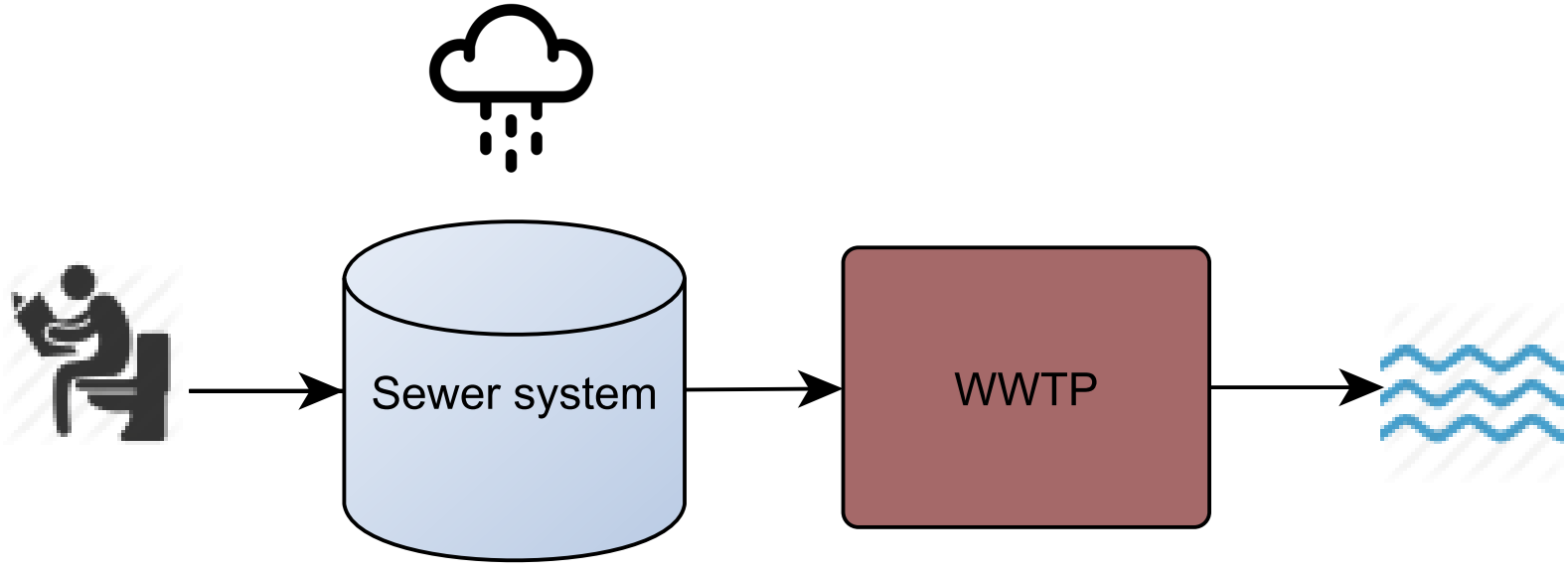
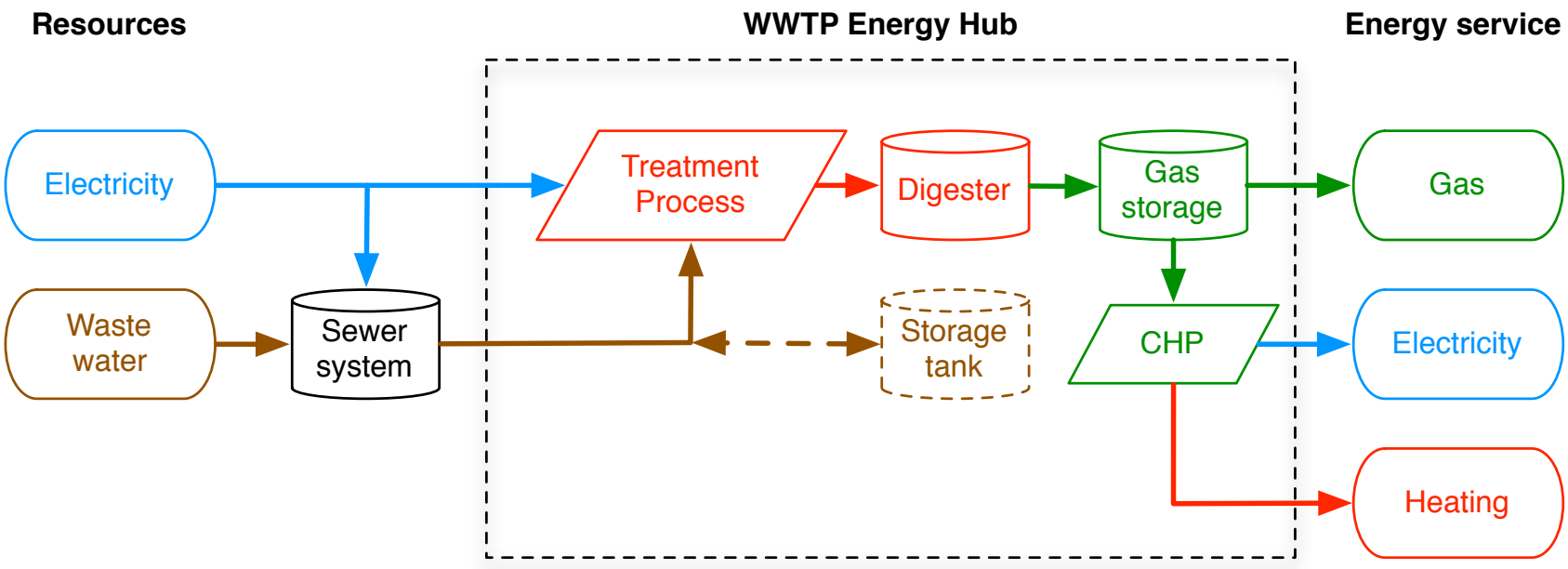
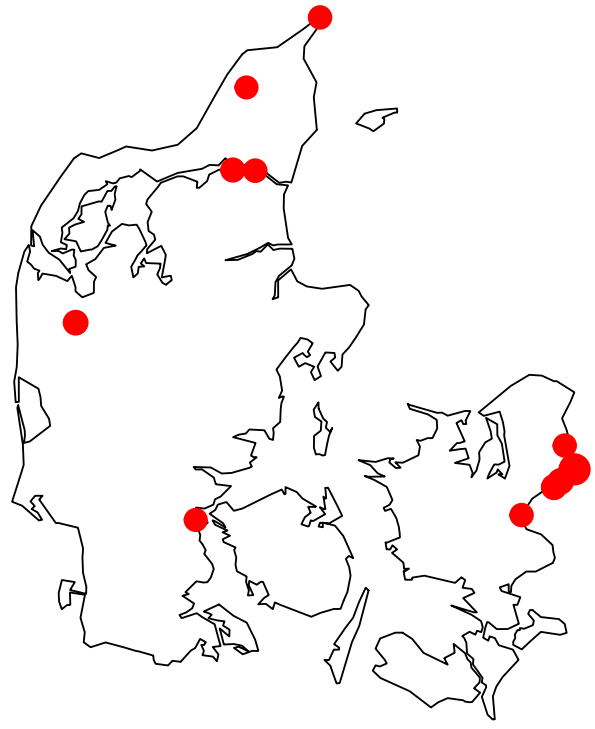
Waste Water Treatment Plant (WWTP)



Waste-2-Energy



10 largest Krüger controlled WWTPs in DK



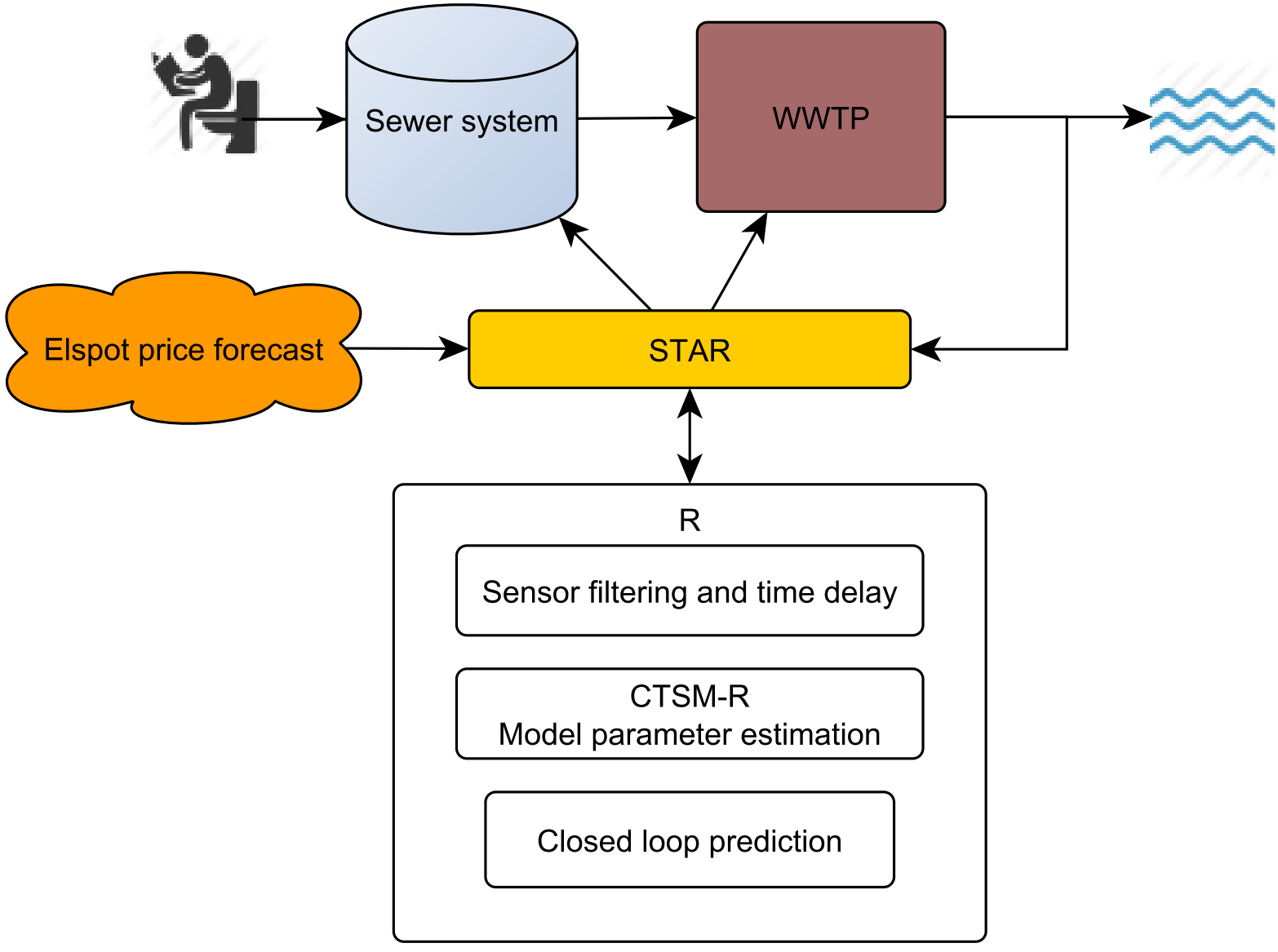
Kolding WWTP

Energy flexibility in waste water treatment and transport

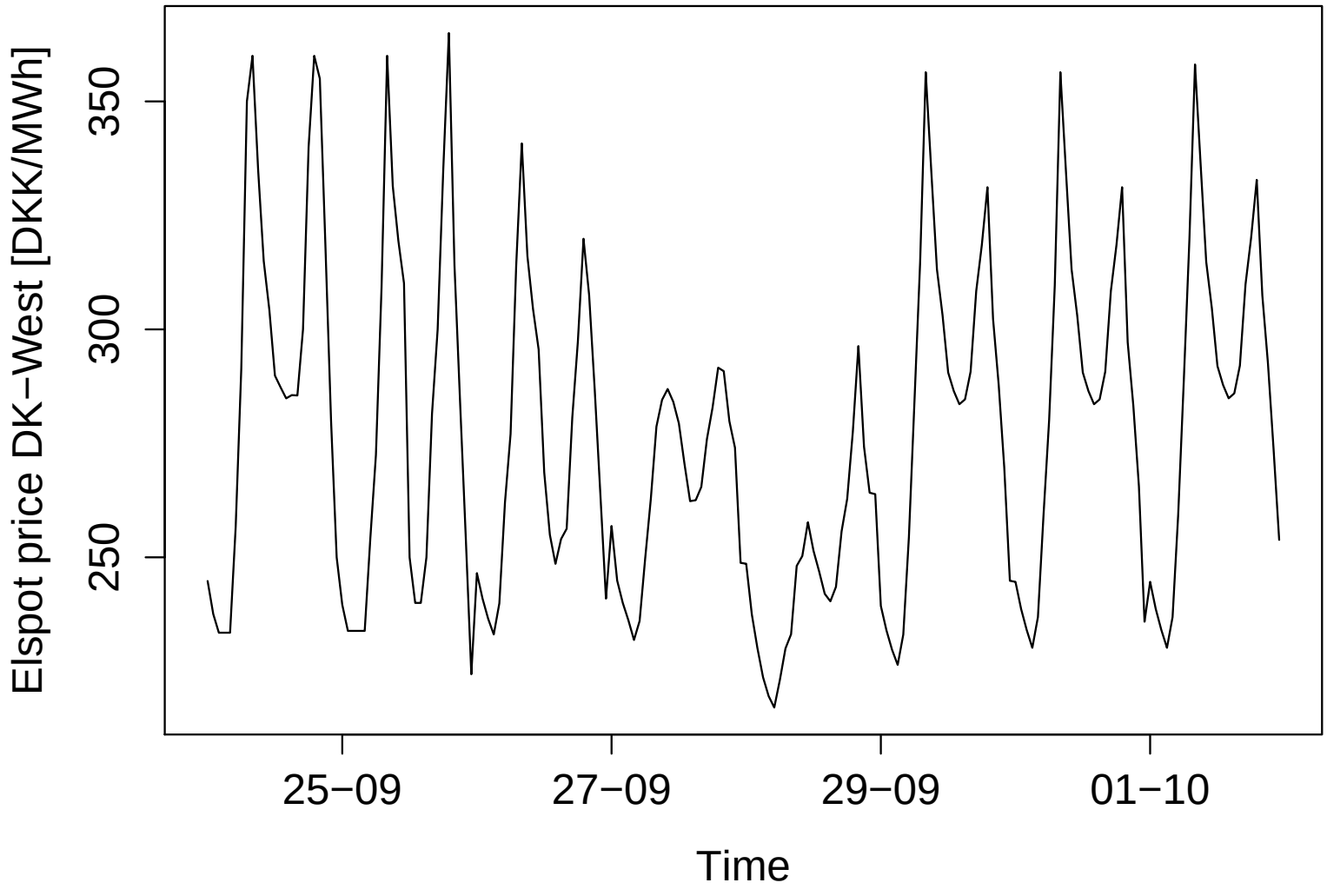
Overall goal: minimize effluent concentrations and overflow risk

1. Sludge $\rightarrow$ biogas $\rightarrow$ gas turbine $\rightarrow$ electricity
2. Power management of the aeration process (720 kW; $>$50%)
3. Pumps and rain water storage in sewer system

WWTP control architecture



Elspot prices



WWTP control goal

$$\text{minimize } p_{fee} Q^T S_N + p_{elspot}^T u$$

Activated Sludge Model (ASM) no. 1

$$\dot{S}_{NH} = -i_{XB}\left(\rho_1 + \rho_2\right) - \left(i_{XB} + \frac{1}{Y_A}\right)\rho_3 + k_a S_{ND} X_{B,H}$$

$$\dot{S}_{NO} = -\frac{1 - Y_H}{2.68\, Y_H}\rho_2 + \frac{1}{Y_A}\rho_3$$

$$\dot{S}_{O} = -\frac{1 - Y_H}{Y_H}\rho_1 - \frac{4.57 - Y_A}{Y_A}\rho_3$$

$$\dot{S}_{S} = \rho_7 - \frac{1}{Y_H}\left(\rho_1 + \rho_2\right)$$

$$\dot{X}_{S} = (1 - f_p)(b_H X_{B,H} + b_A X_{B,A}) - \rho_7$$

$$\dot{X}_{B,H} = \rho_1 + \rho_2 - b_H X_{B,H}$$

$$\dot{X}_{B,A} = \rho_3 - b_A X_{B,A}$$

$$\dot{S}_{ND} = \rho_8 - k_a S_{ND} X_{B,H}$$

$$\dot{X}_{ND} = (i_{XB} - f_p i_{XP})(b_H X_{B,H} + b_A X_{B,A}) - \rho_8$$

(S_I, X_I, X_P, and S_{ALK})

Activated Sludge Model (ASM) no. 1 - reaction rates

$$\rho_1 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{S_O}{K_{O,H} + S_O} X_{B,H}$$

$$\rho_2 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \eta_g X_{B,H}$$

$$\rho_3 = \hat{\mu}_A \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{O,A} + S_O} X_{B,A}$$

$$\rho_7 = k_h \frac{X_S/X_{B,H}}{K_X + X_S/X_{B,H}} \left(\frac{S_O}{K_{O,H} + S_O} + \eta_h \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \right) X_{B,H}$$

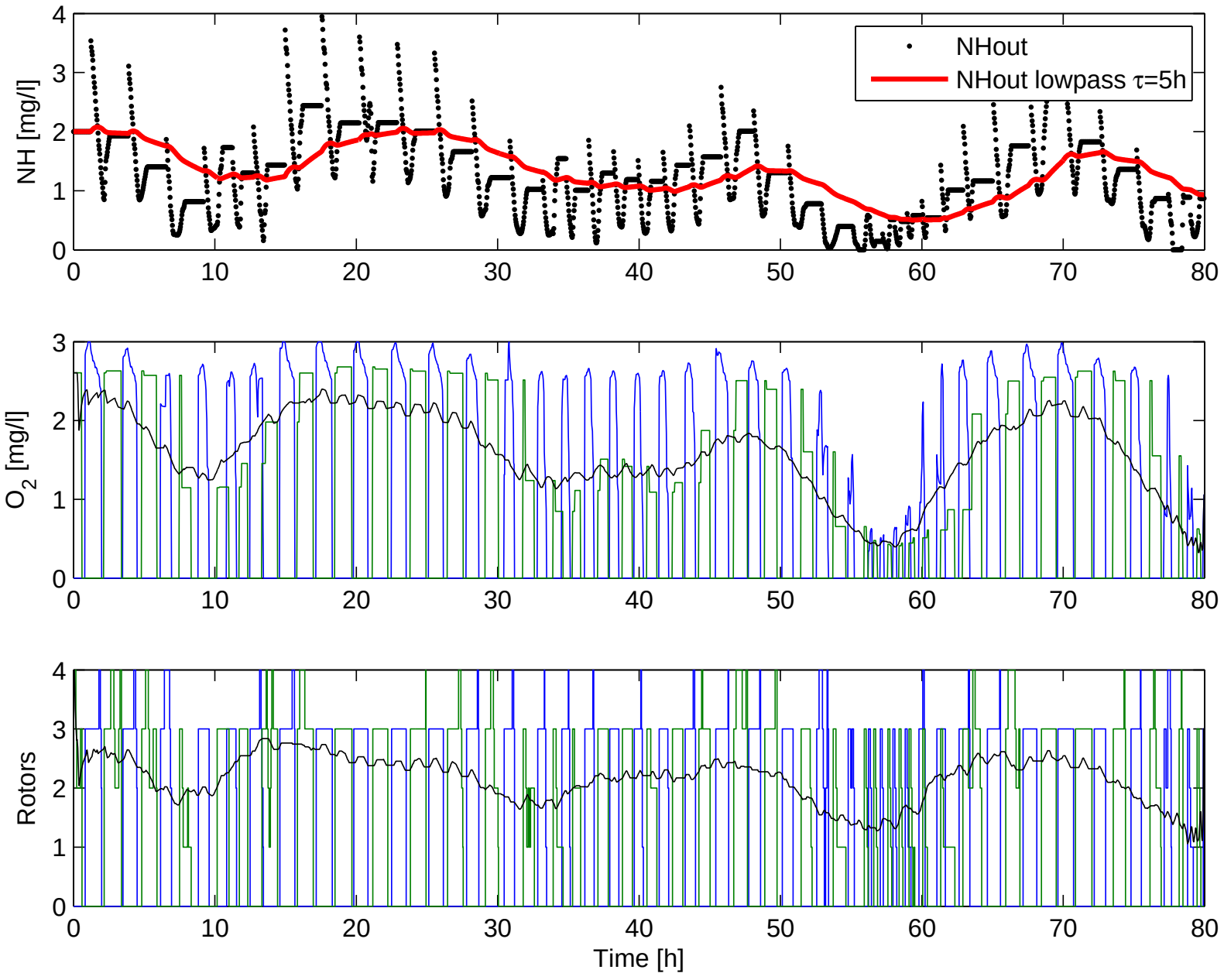
$$\rho_8 = \rho_7 \left(X_{ND}/X_S \right)$$

Reduced ASM1 - time-varying linear model

$$\dot{S}_{NH} = \theta^{+}_{NH} Q(t) w_i - \theta^{-}_{NH} O$$
$$\dot{S}_{NO} = -\theta^{-}_{NO} w_i + \theta^{+}_{NO} O$$

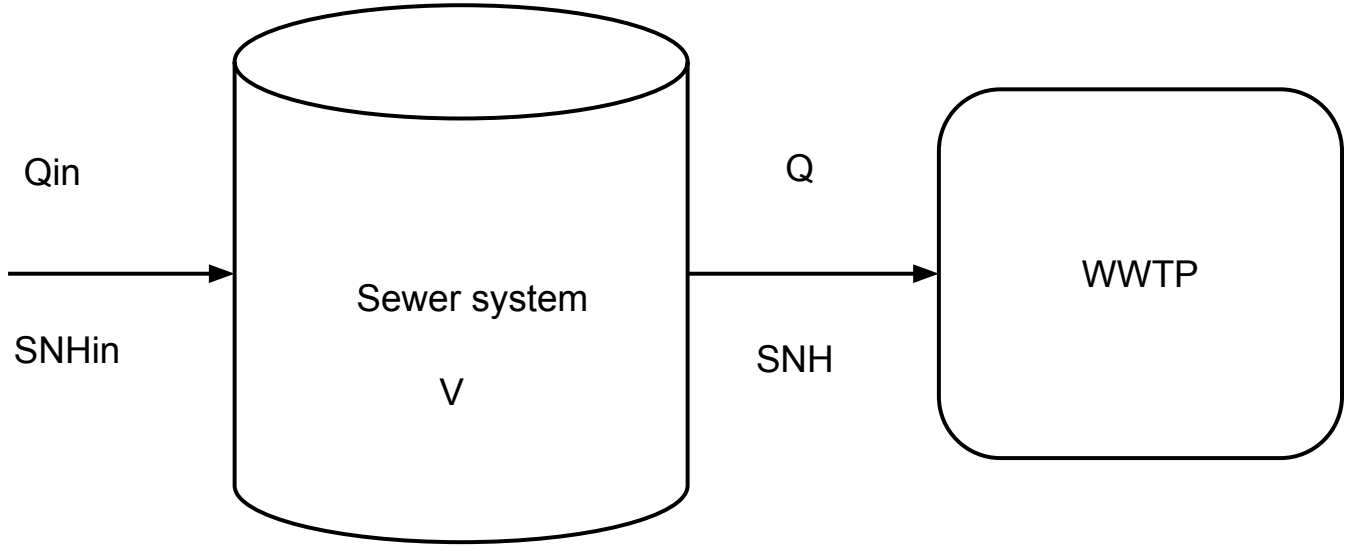
$$(S_{NH}, S_{NO}) \geq 0$$

Aeration control

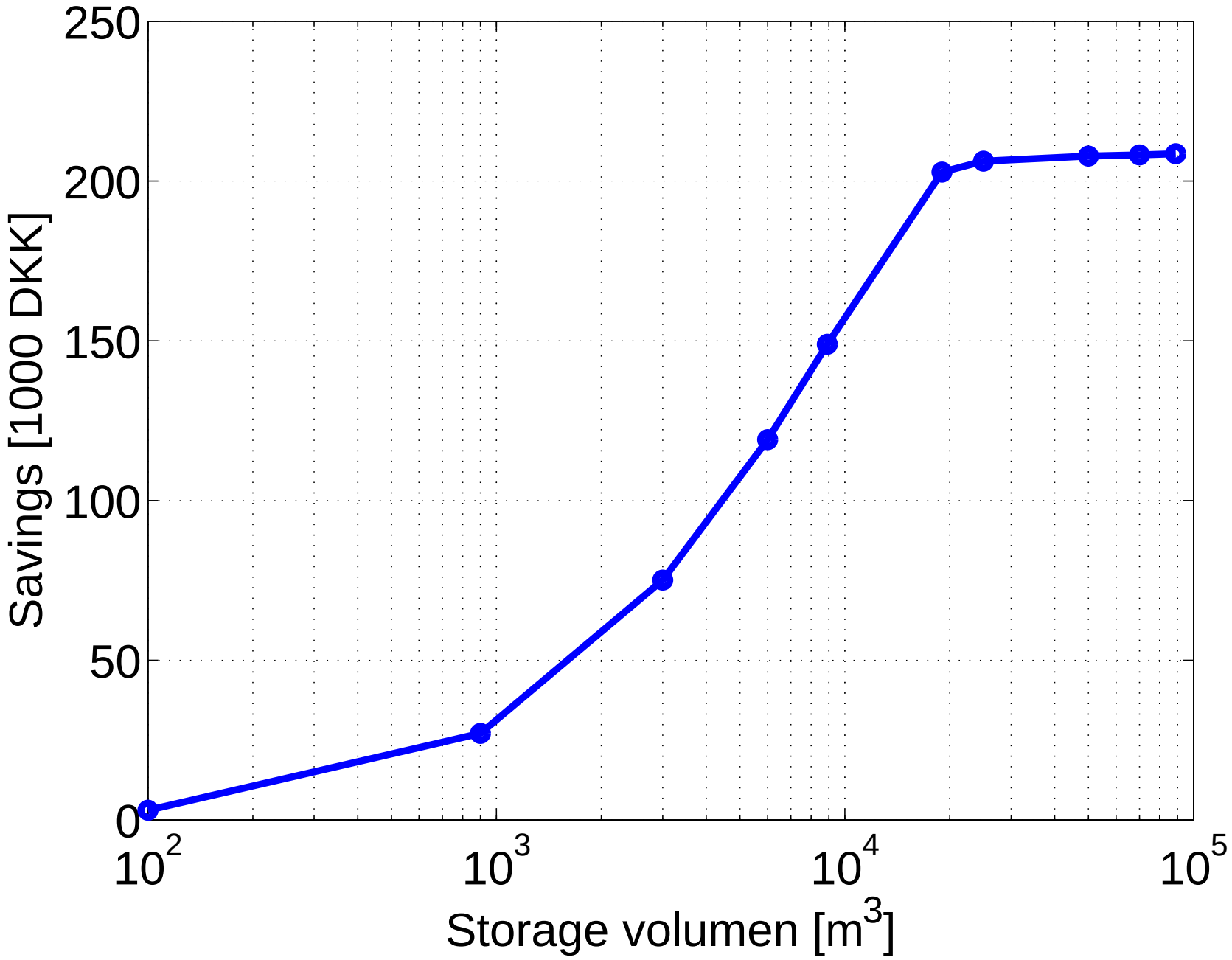


Sewer system control goal

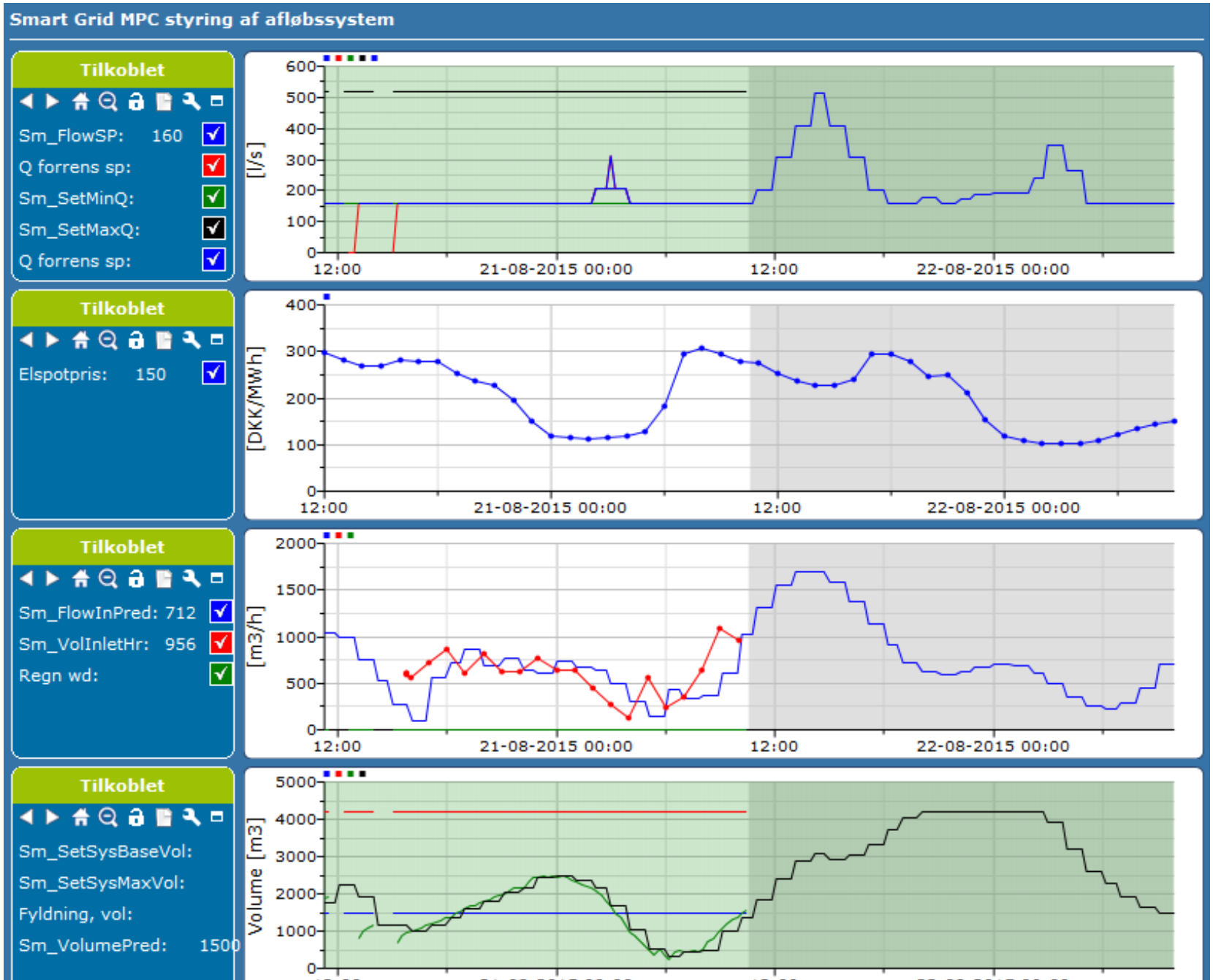
$$\text{minimize overflow} + p_{elspot}^{T} f(Q)$$



Sewer system annual Elspot savings



Online test


Smart Grid MPC styring af afløbssystem
Tilkoblet
Sm_FlowSP: 160
Q forrens sp:
Sm_SetMinQ:
Sm_SetMaxQ:
Q forrens sp:
[l/s]
600
500
400
300
200
100
0
12:00
21-08-2015 00:00
12:00
22-08-2015 00:00
Tilkoblet
Elspotpris: 150
[DKK/MWh]
400
300
200
100
0
12:00
21-08-2015 00:00
12:00
22-08-2015 00:00
Tilkoblet
Sm_FlowInPred: 712
Sm_VolInletHr: 956
Regn wd:
[m3/h]
2000
1500
1000
500
0
12:00
21-08-2015 00:00
12:00
22-08-2015 00:00
Tilkoblet
Sm_SetSysBaseVol:
Sm_SetSysMaxVol:
Fyldning, vol:
Sm_VolumePred: 1500
Volume [m3]
5000
4000
3000
2000
1000
0

WWTP Smart Grid challenges

- $(cost_{effluents}, cost_{overflow}) \gg cost_{electricity}$ (trade-off)
- Complex nonlinear time-varying treatment process (sensors = \$)
- Time scale perspective (different markets and control handles)

Future work

- Energy management of flexible waste water treatment plants
- Control integration of sewer system and WWTP
- More demonstrations
- Interface to power markets or aggregators
- WWTP aggregation strategies

Questions and Comments

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