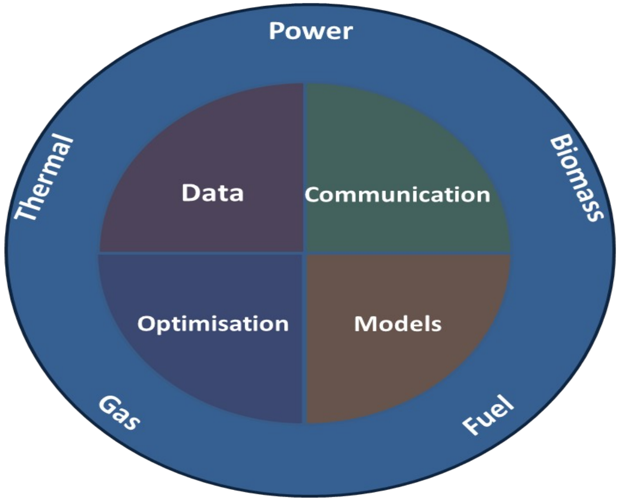
Wastewater Treatment and Energy Flexibility, CITIES and Kolding WWTP



Henrik Madsen and Rasmus Halvgaard, DTU Compute

http://www.henrikmadsen.org

http://www.smart-cities-centre.org

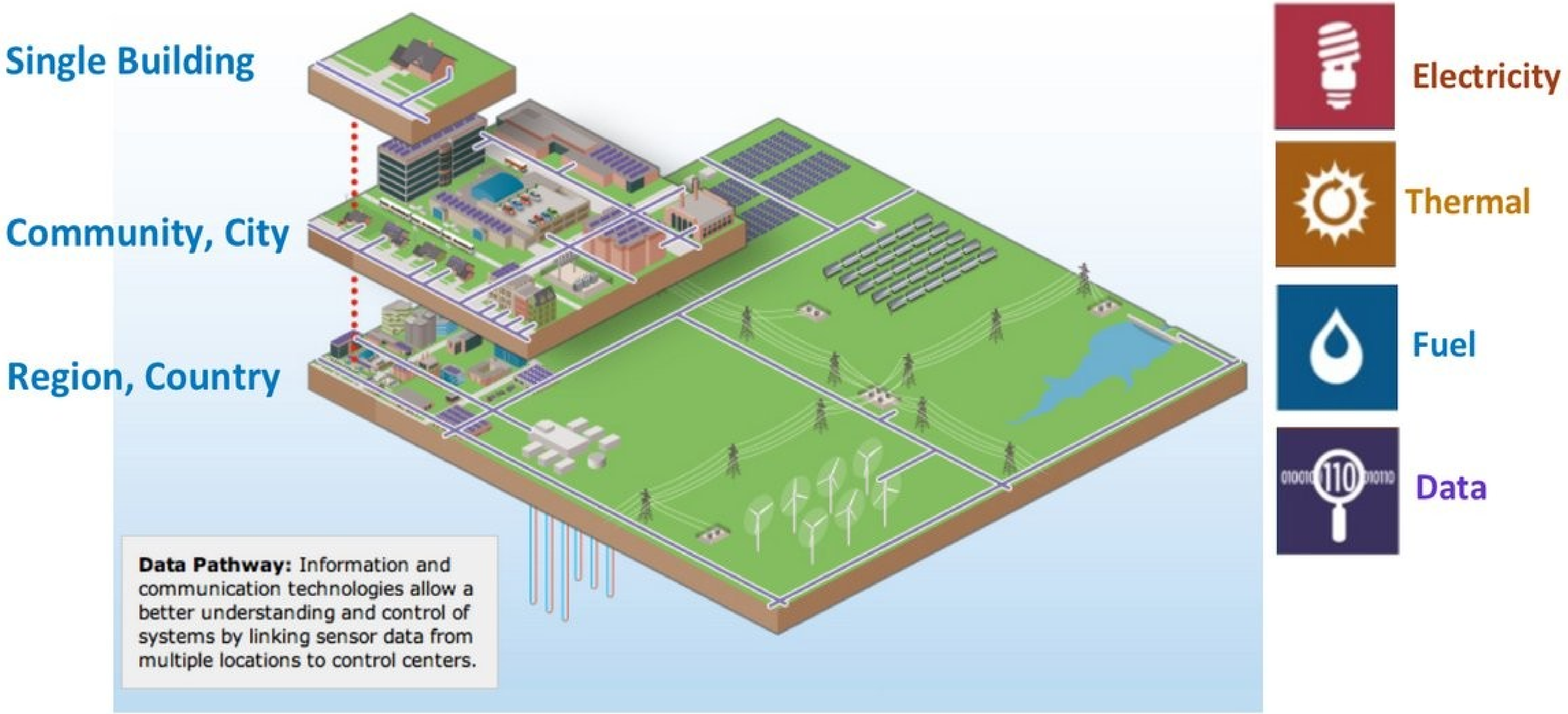
CITIES
Centre for IT Intelligent Energy Systems

Contents

- Center for IT-Intelligent Energy Systems (CITIES)
- Smart-Energy Operating System (SE-OS)
- Modelling for Energy Flexibility Operations
- Energy Flexibility and Wastewater
- Kolding WWTP implementation
- New large H2020 project – SmartNet
- Other international activities

Energy Systems Integration

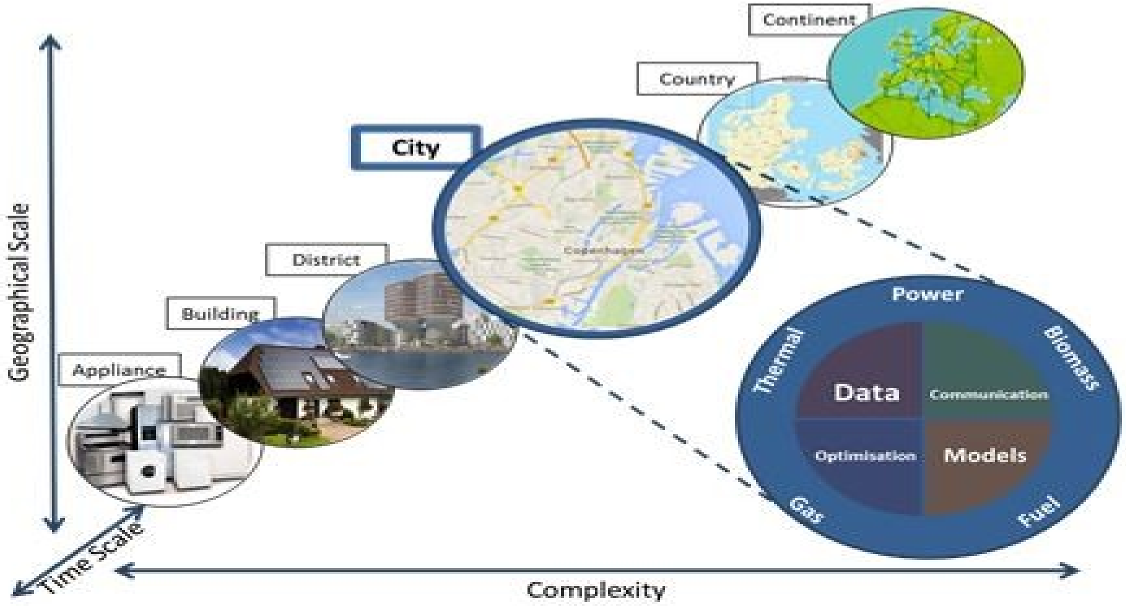
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



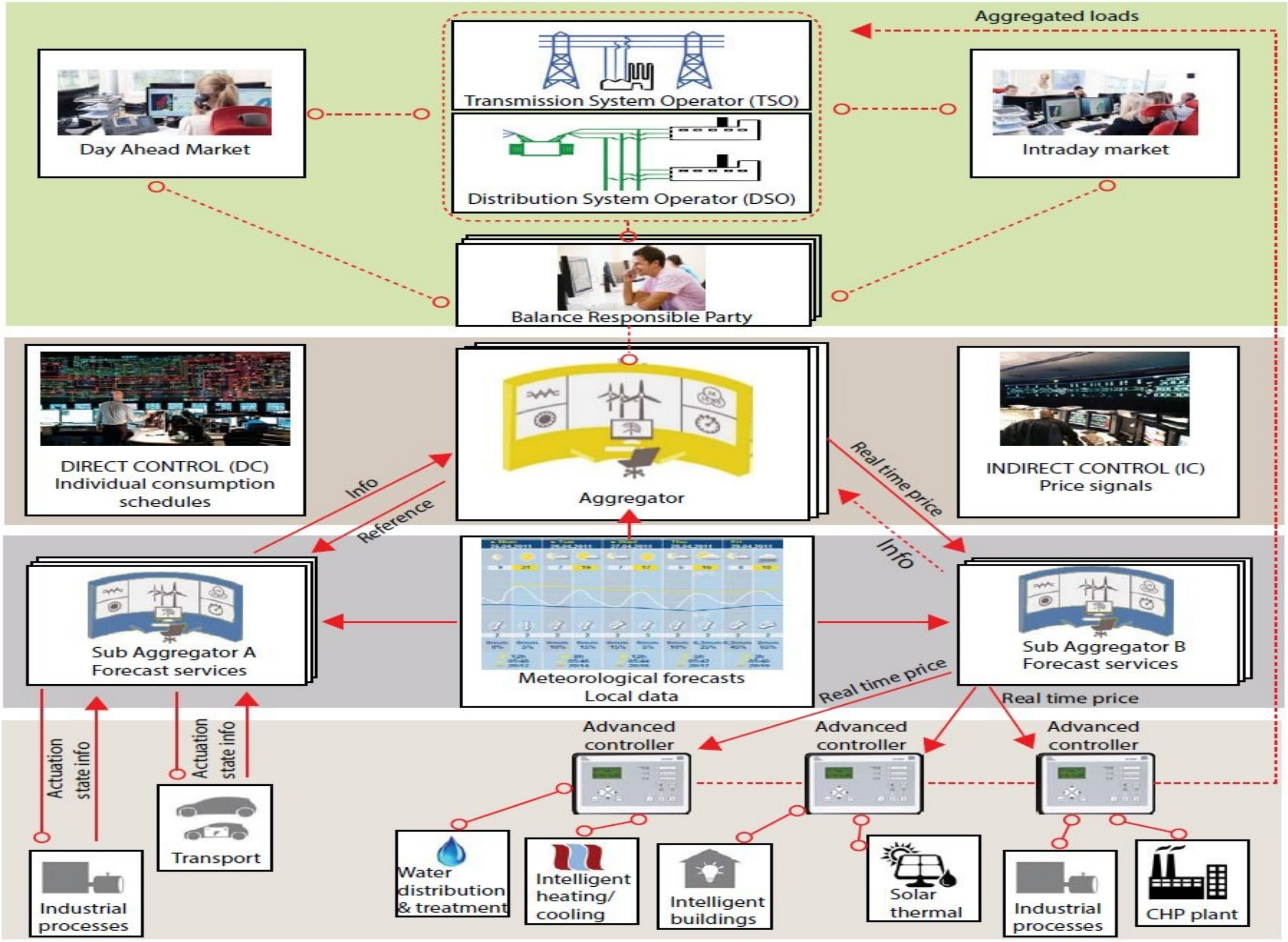
Intelligent Integration and CITIES

Center for IT-Intelligent Energy Systems (CITIES) is establishing ICT solutions for **design and operation of integrated electrical, thermal, fuel pathways at all scales**.

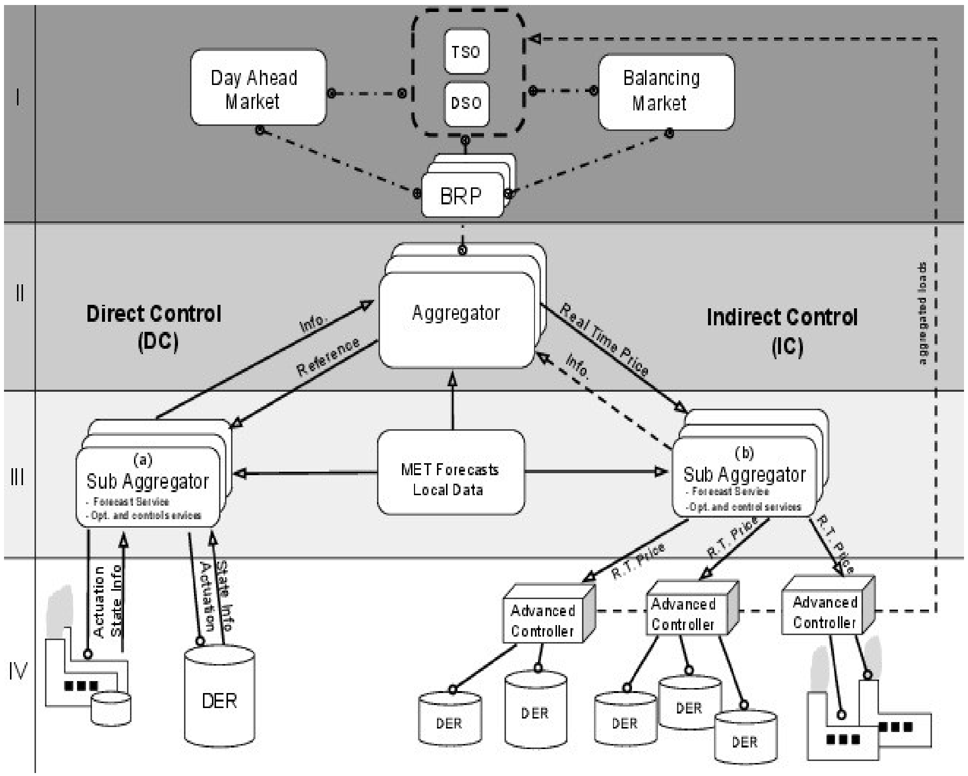
CITIES is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org .



Energy-System OS



Optimization in ES-OS



In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

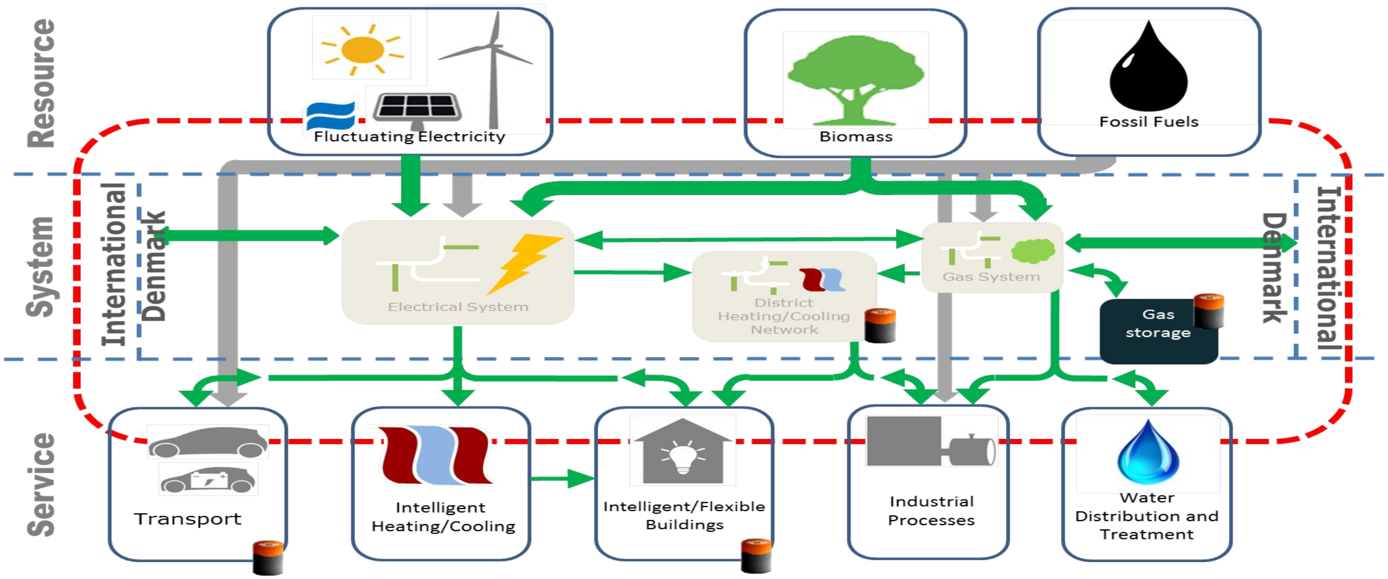
Simple 'contracts'

Direct vs Indirect Control

Table 3 – Difference between direct (DC) and indirect (IC) control.

<table>
<tr><th>Level</th><th>Direct Control (DC)</th><th>Indirect Control (IC)</th></tr>
<tr><td>III</td><td rowspan="2">$\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k})$
$\downarrow_{u_1} \cdots \downarrow_{u_J} \quad \uparrow_{x_1} \cdots \uparrow_{x_J}$
s.t. $x_{j,k+1} = f_j(x_{j,k}, u_{j,k}) \quad \forall_j \in J$</td><td>$\min_{\hat{z},p} \sum_{k=0}^{N} \phi\ (\hat{z}_k, p_k)$
s.t. $\hat{z}_{k+1} = f(p_k)$</td></tr>
<tr><td>IV</td><td>$\min_u \sum_{k=0}^{N} \phi_j(p_k, u_k) \qquad \forall_j \in J$
s.t. $x_{k+1} = f_j(x_k, u_k)$</td></tr>
</table>

Grey-box Modelling and Virtual Storage Principles



- **Grey-box modelling is an essential tool for implementing energy flexible solutions**
- **(Virtual) storage principles:**
  - Buildings (thermal mass) can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

Price-based Control of Power Load

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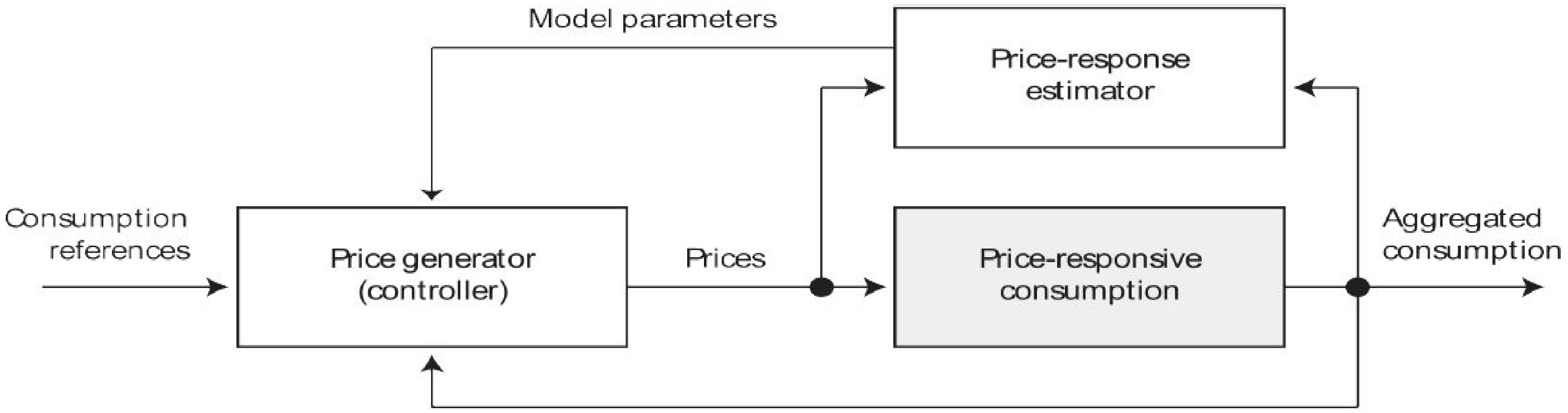
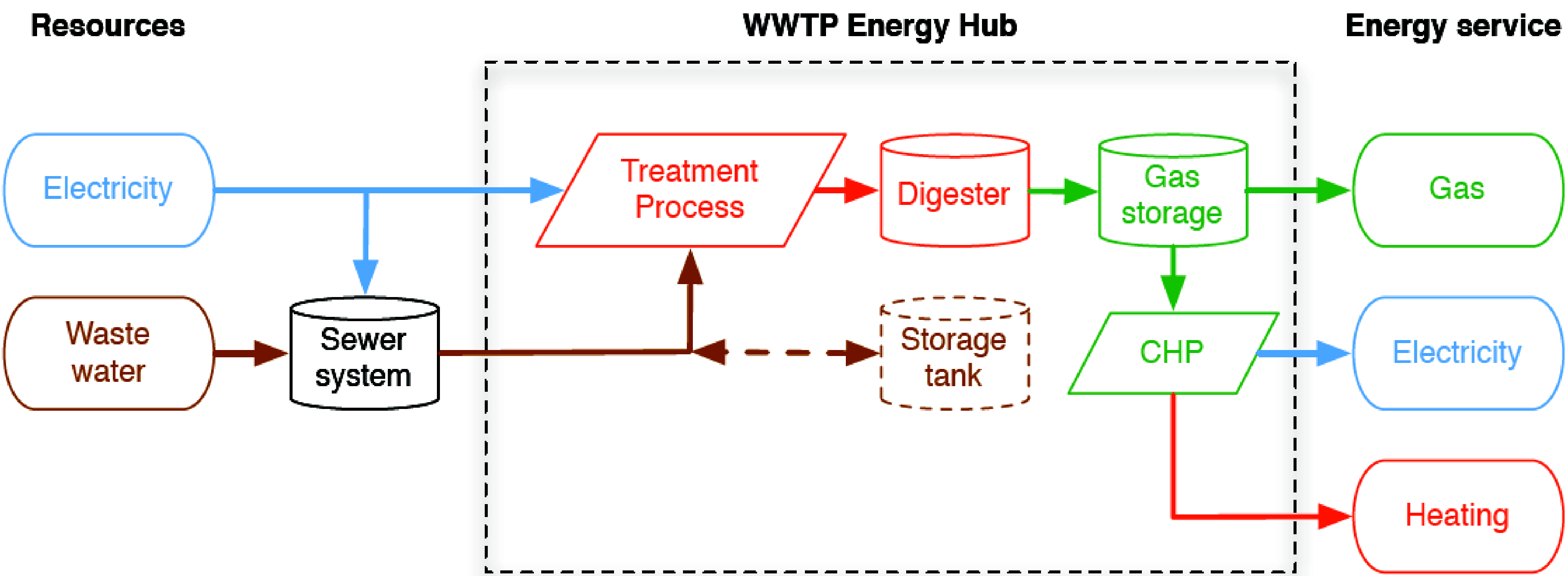
Price-based Control of Power Load



Case study

Control of Wastewater Treatment Plants

Waste-2-Energy



Kolding WWTP

Energy Flexibility in Wastewater Treatment

- Sludge -> Biogas -> Gas turbine ->Electricity
- Power management of the aeration process
- Pumps and storage in sewer system

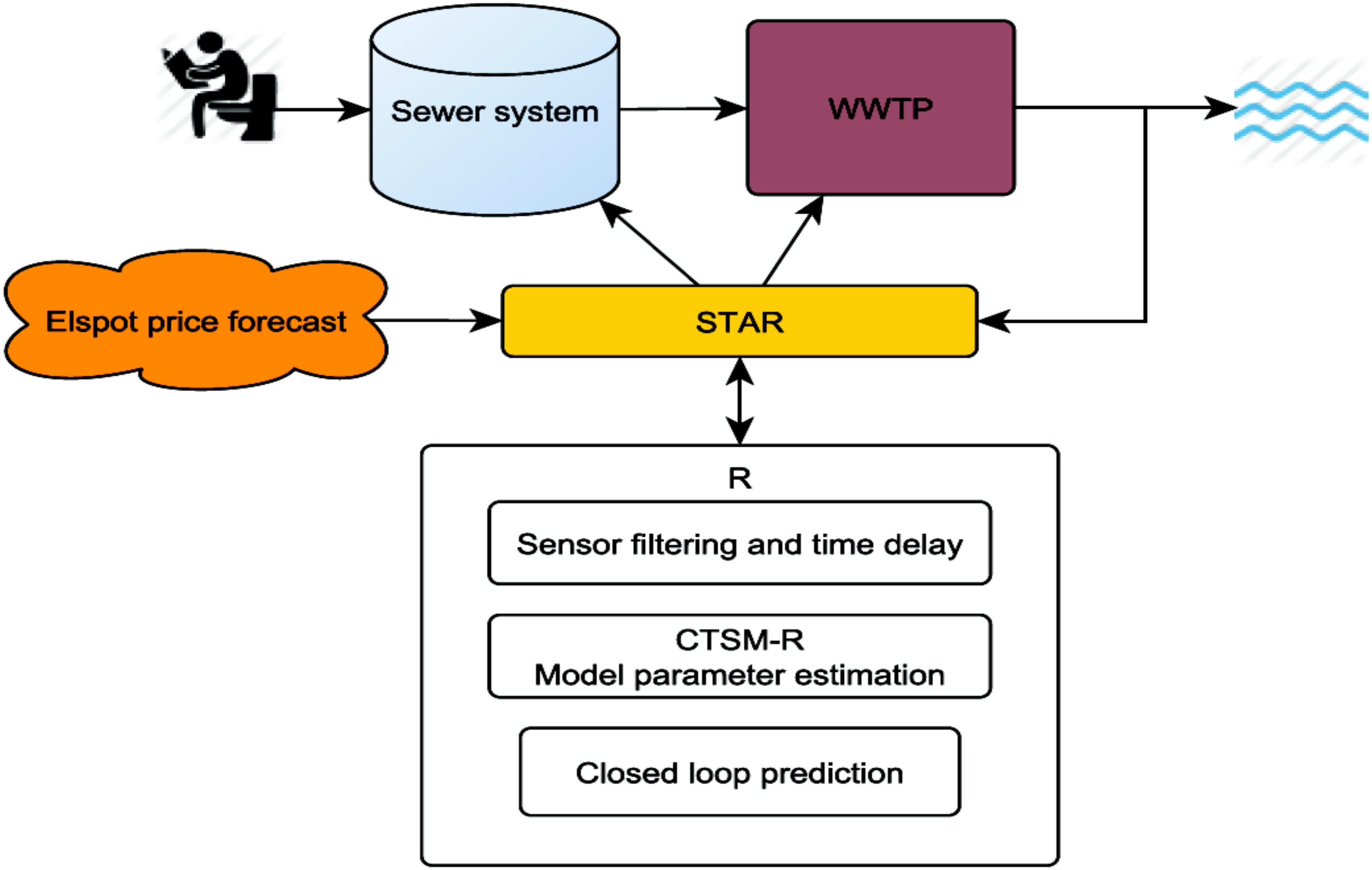
Overall goals:

Cost reduction

Minimize effluent concentration

Minimize overflow risk

Energy Flexibility in Wastewater Treatment



WWTP Control goal

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

Activated Sludge Model (ASM) No. 1

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

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

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

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

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

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

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

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

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

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

Reaction Rates in ASM No. 1

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

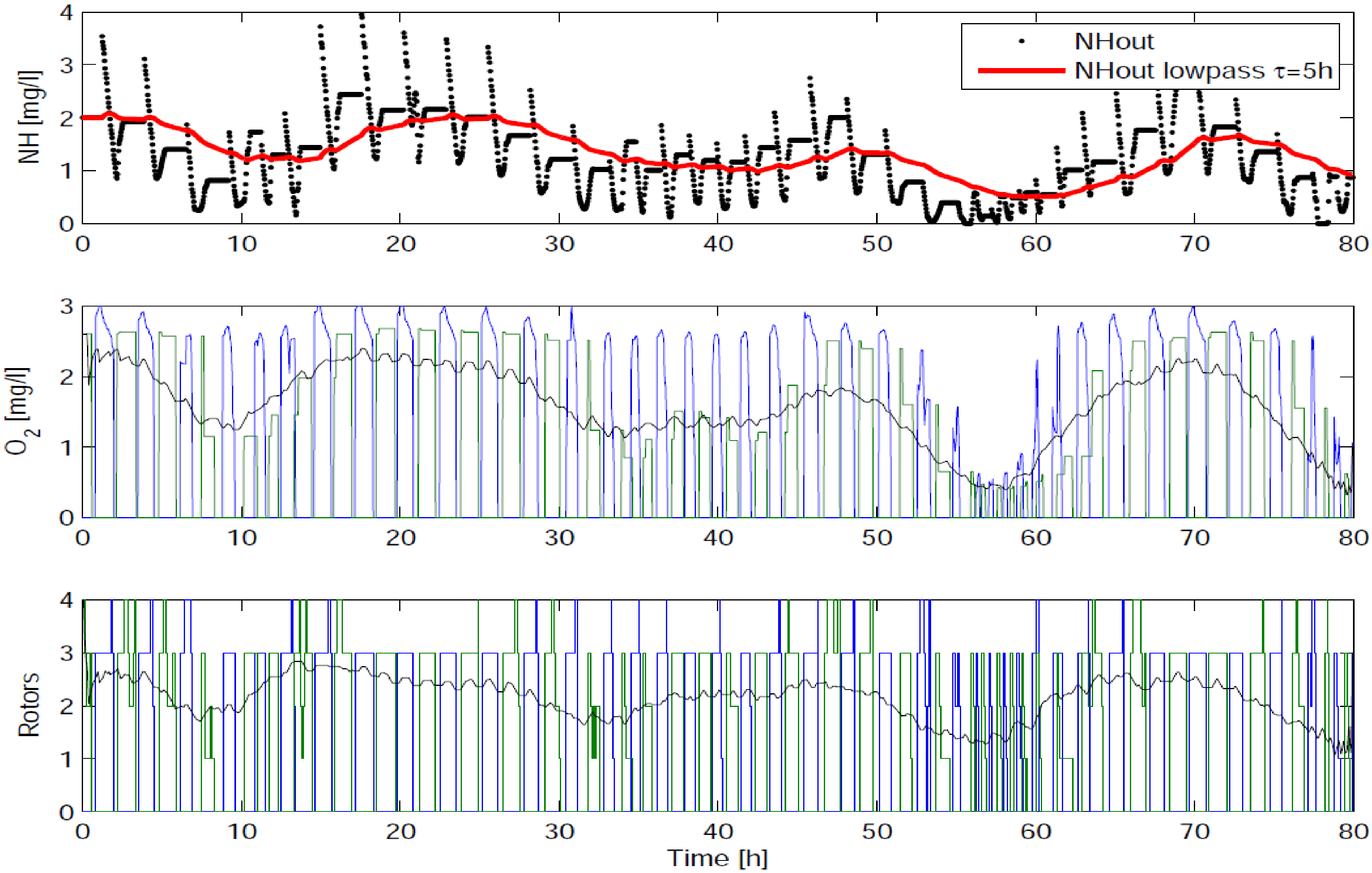
$$\rho_2 = \hat{\mu}_H \frac{S_S}{K_S + S_S} \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_{NO}}{K_{NO} + S_{NO}} \eta_g X_{B,H}$$

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

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

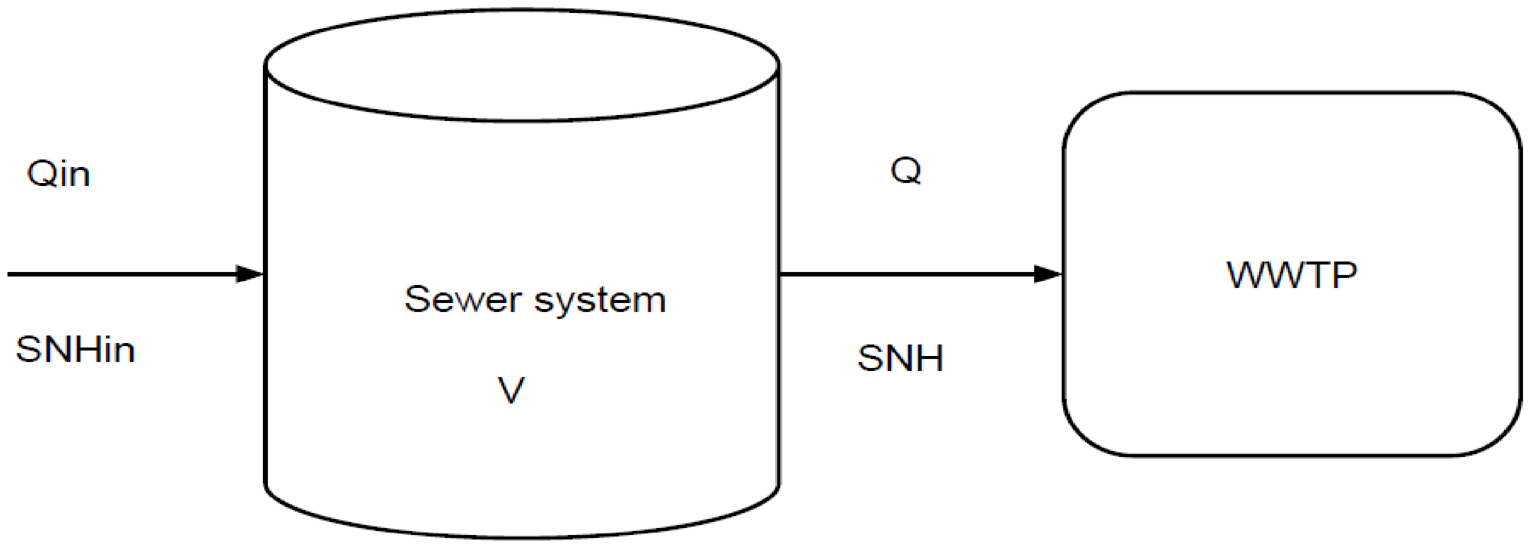
$$\rho_8 = \rho_7 \left(X_{ND}/X_S \right)$$

Aeration Control

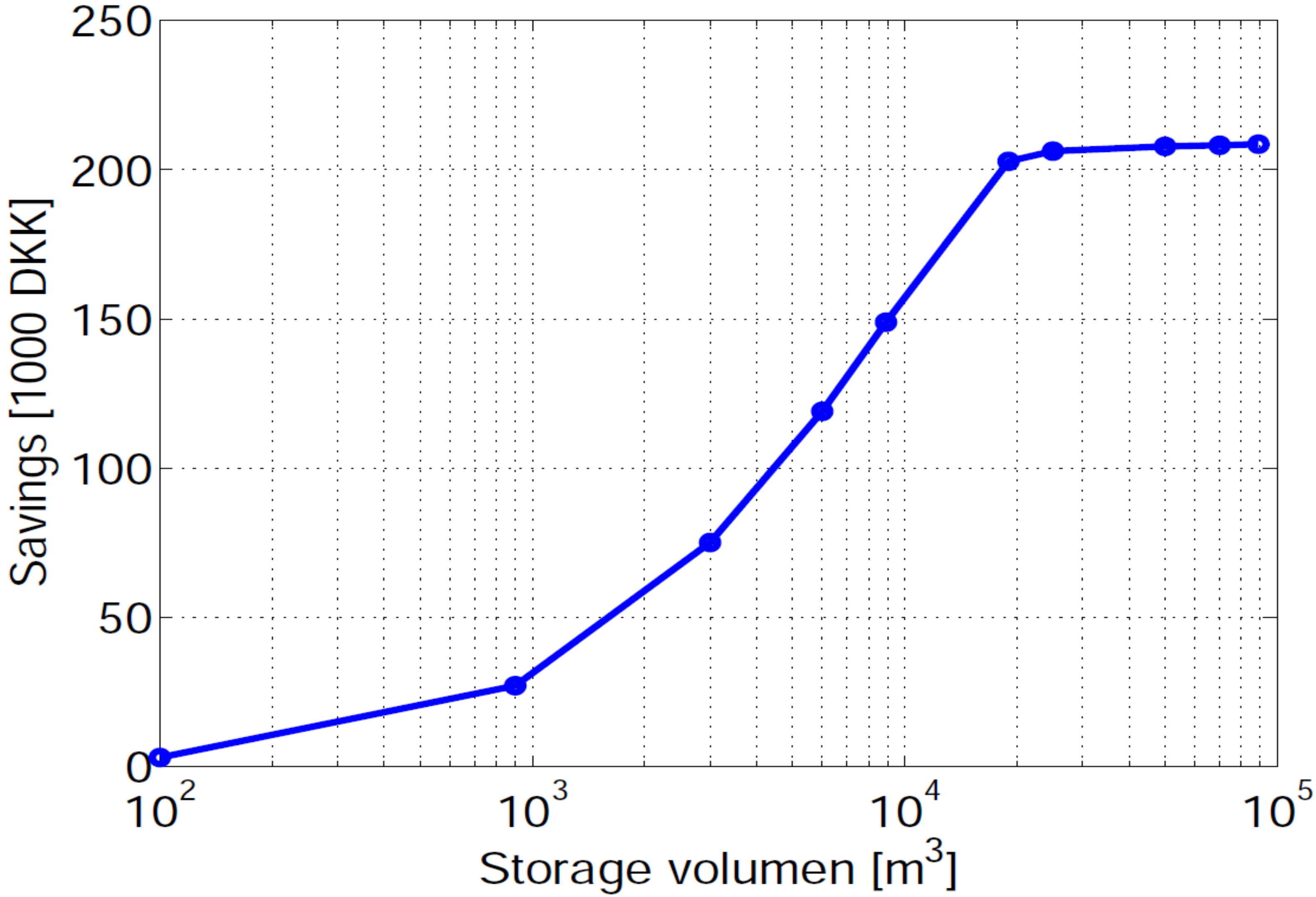


Sewer System Control Goal

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



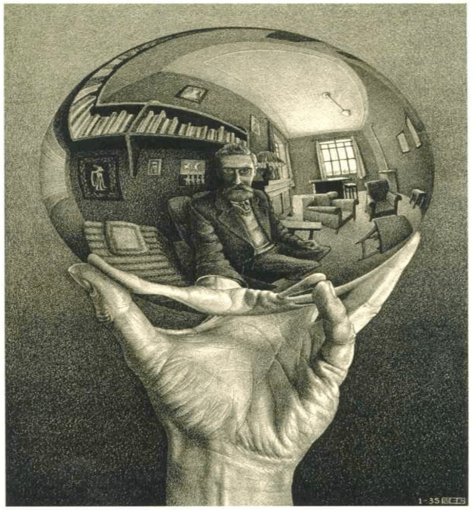
Sewer System Annual Elspot Savings



Some Energy Flexibility Sub-Projects in CITIES

Energy Flexibility
Some Demo Projects in CITIES

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, Nyfors, ..)
- Green Houses (NeoGrid, ENFOR, ...)
- CHP (Dong Energy, EnergiFyn, ...)
- Industrial production
- VE (charging)
- ....



CITIES

Centre for IT-Intelligent Energy Systems in cities

Demo projects | Software solutions | Work Packages | Partners | Events | Communications | Publications | Vacant positions | Contacts

Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available at GitHub.

Search ...

Latest news

Ambassador Louise Bang Jespersen visited CITIES, October 29th 2015

CITIES Korean International Workshop – KIER, Daejeon, Korea, October 22nd 2015

Workshop on Mathematical Sciences Collaboration in Energy Systems Integration – DTU,

H2020 SmartNet - Flexibility Models

Demand response	Industrial	Core industrial processes with flexibility	electrolysis,cement and paper mills, electric arc furnaces,...
		Auxiliary processes	lighting, electrical engines, compressed air, pumps, IT
		HVAC	heating, cooling, ventilation, air conditioning
		All/General	
	Commercial	HVAC	heating, cooling, ventilation, air conditioning
		All/General	
	Residential	HVAC	heating, cooling, ventilation, air conditioning
		Household appliances	dishwashers, washing machines,...
		All/General	
	Power to heat	Direct resistance heating	
		Electric heat pump	
		Other	
	All/General		
Distributed generation	Biogas power plants		
	CHP	Micro-CHP (Residential)	
		District Heating CHP	
		Industrial CHP	
		All/General	
	Active Power Control of Renewable Energy	Wind turbines	
		Solar PV	
		Other	
	Fuel cells		
	Emergency backup systems		
	All/General		
Distributed storage	Pumped hydro storage		
	Compressed air energy storage		
	Flywheels		
	Batteries		Li-ion, Redox flow, Lead acid, NaS
	Power to gas		
	All/General		
Electric vehicles	V2G (Vehicle to grid)		
	G2V (Grid to vehicle)		

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International Alliances on Energy Systems Integration

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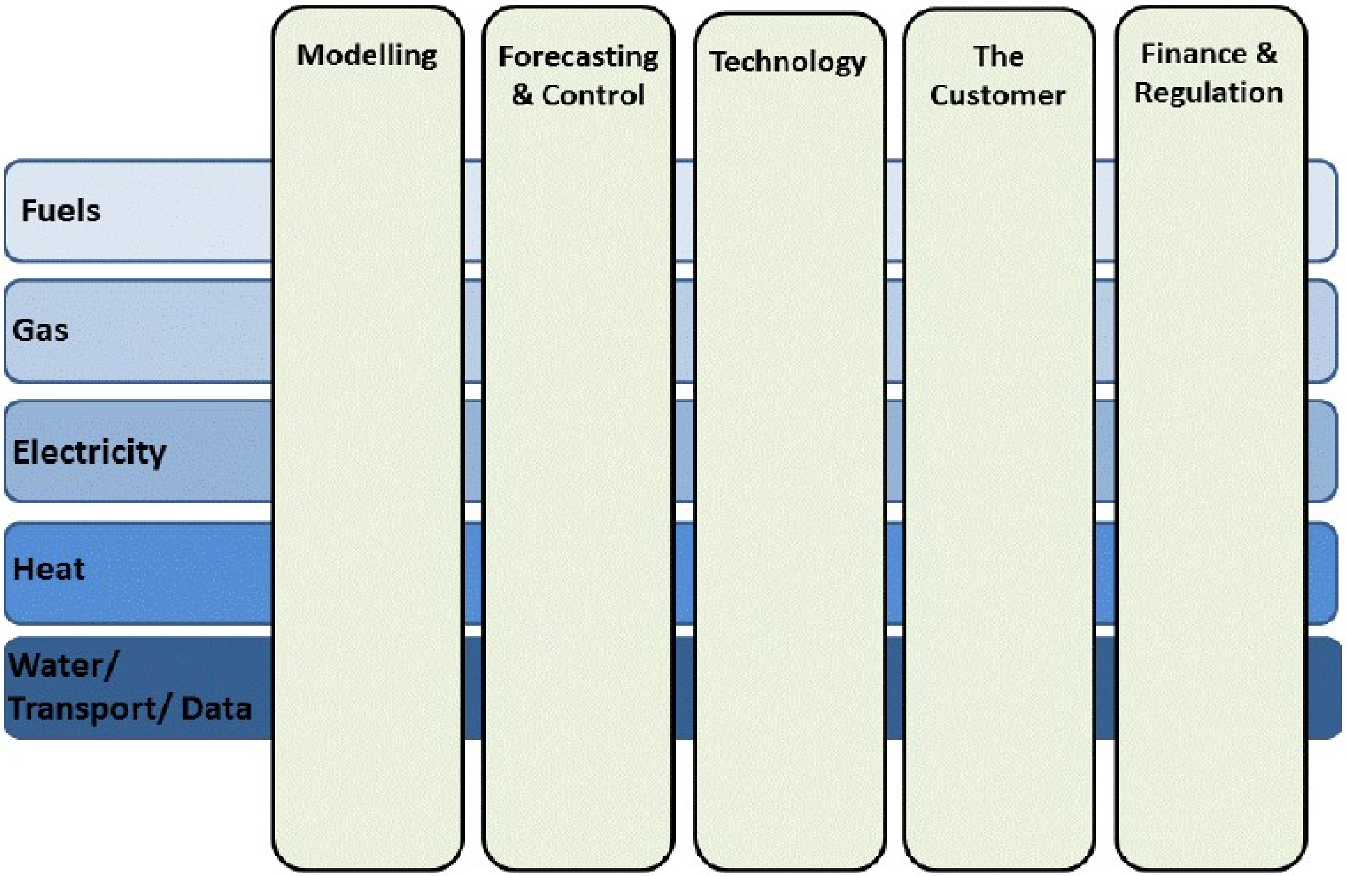
News (DTU Compute is leading):
ESI Joint Program in EERA



Foster a Global Community

www.iiesi.org

iiESI International Institute™ for Energy Systems Integration

Vision

A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems

Objectives

- Share ESI knowledge and Experience
- Coordination of R&D activities
- Education and Training Resources

Recent Activities

- 2013 – IEEE P&E Issue on ESI
- 2014 – Four workshops on ESI
- 2015 – ESI 101 and 102 Courses

NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · EPRI ELECTRIC POWER RESEARCH INSTITUTE · UCD DUBLIN · DTU · KU LEUVEN

Thanks for your attention!

For more information:

hmad@dtu.dk