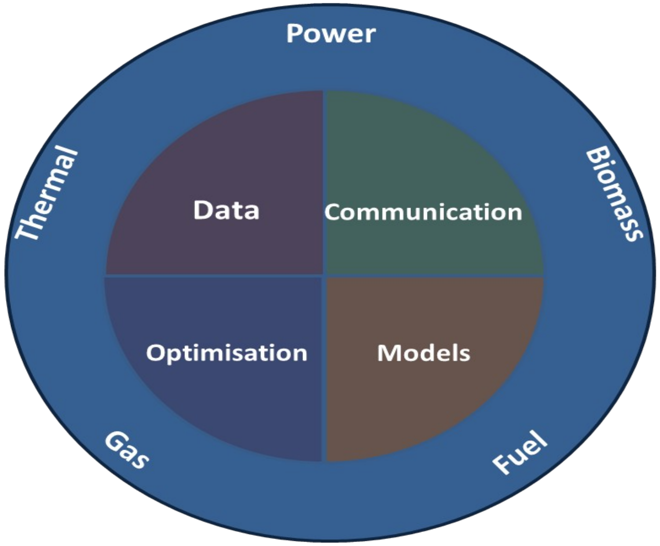
Integrated Energy Systems

Aggregation, Forecasting and Control



Henrik Madsen, DTU Compute

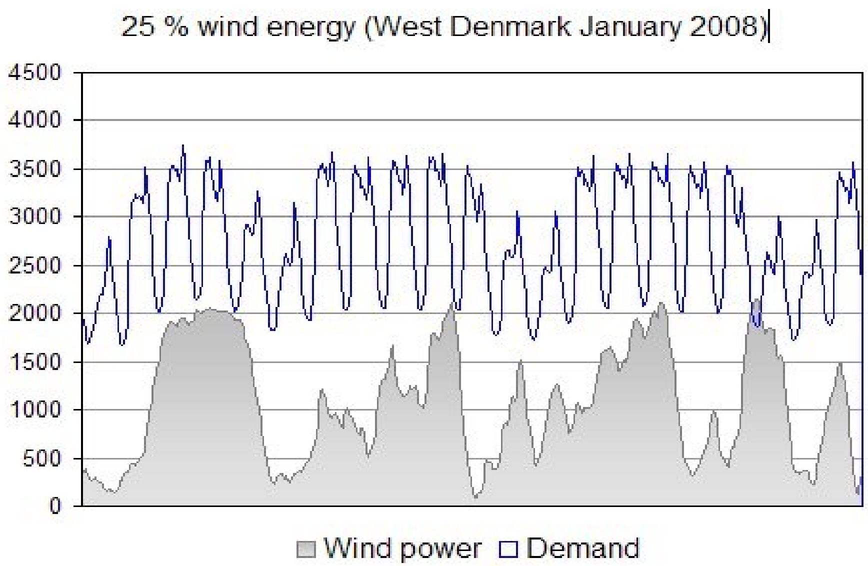
http://www.henrikmadsen.org

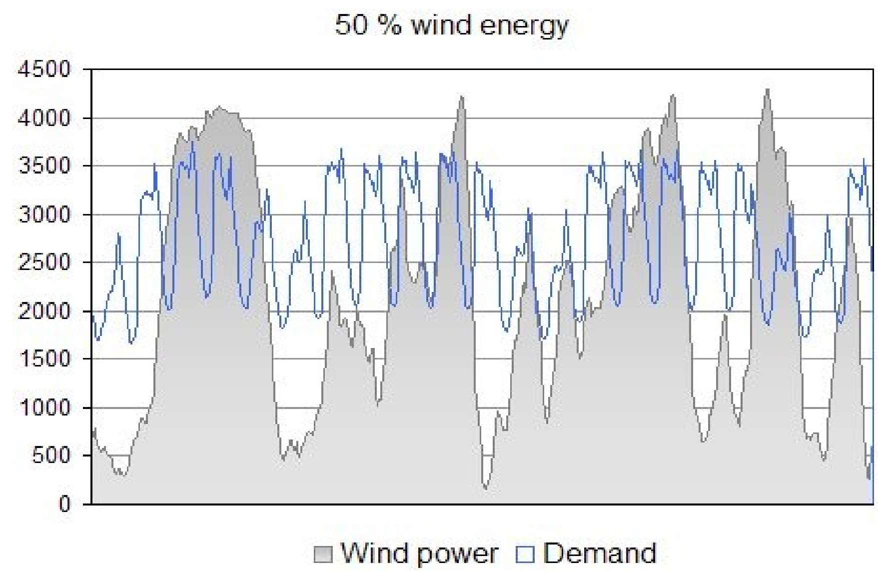
http://www.smart-cities-centre.org

CITIES
Centre for IT Intelligent Energy Systems

The Danish Wind Power Case

.... balancing of the power system





In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

In 2014 more than 40 pct of electricity load was covered by wind power.

For several days in 2014 the wind power production was more than 120 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power

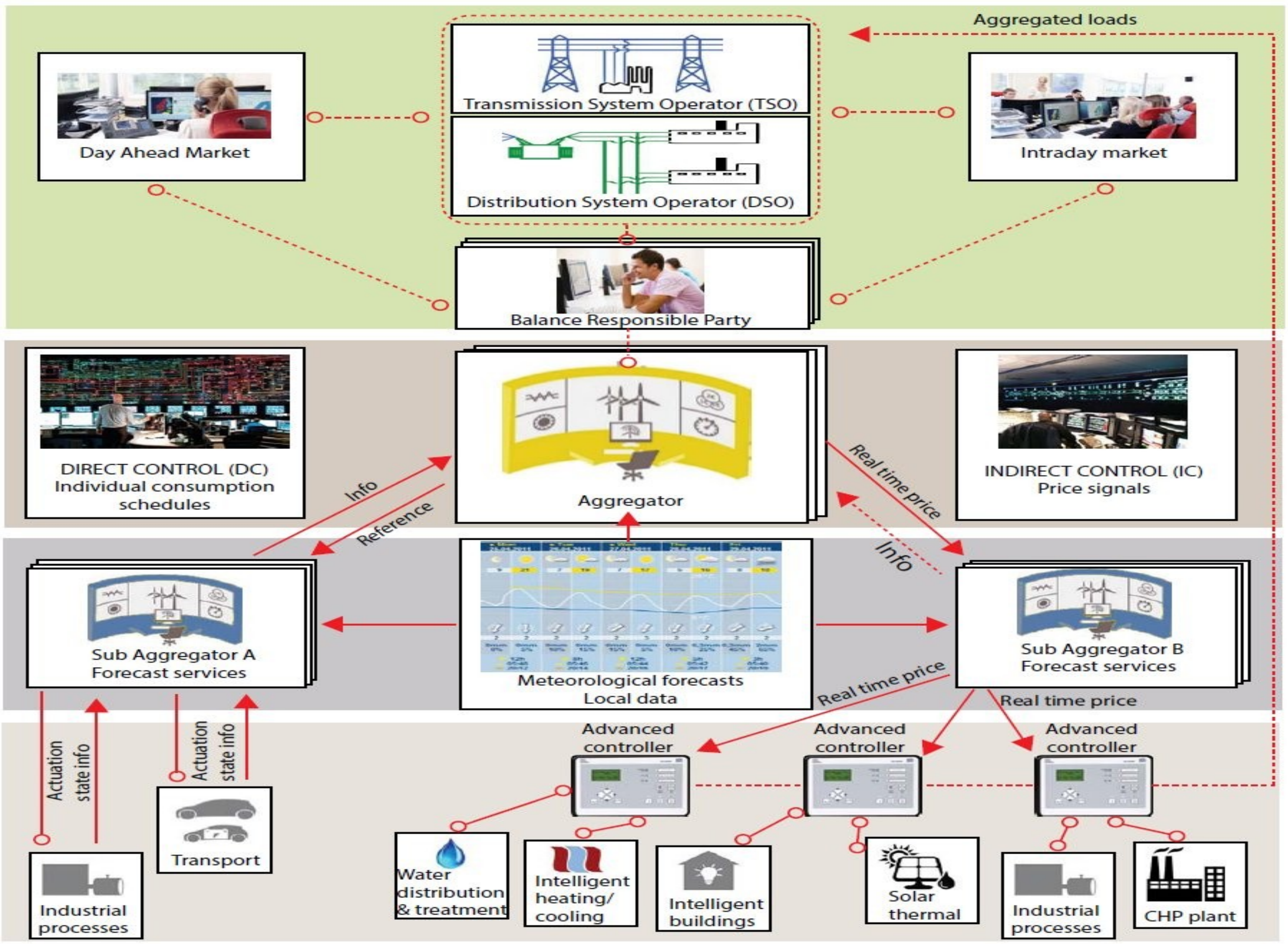
Intelligent Integration and Cities

Cities play an important role – for several reasons ......

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

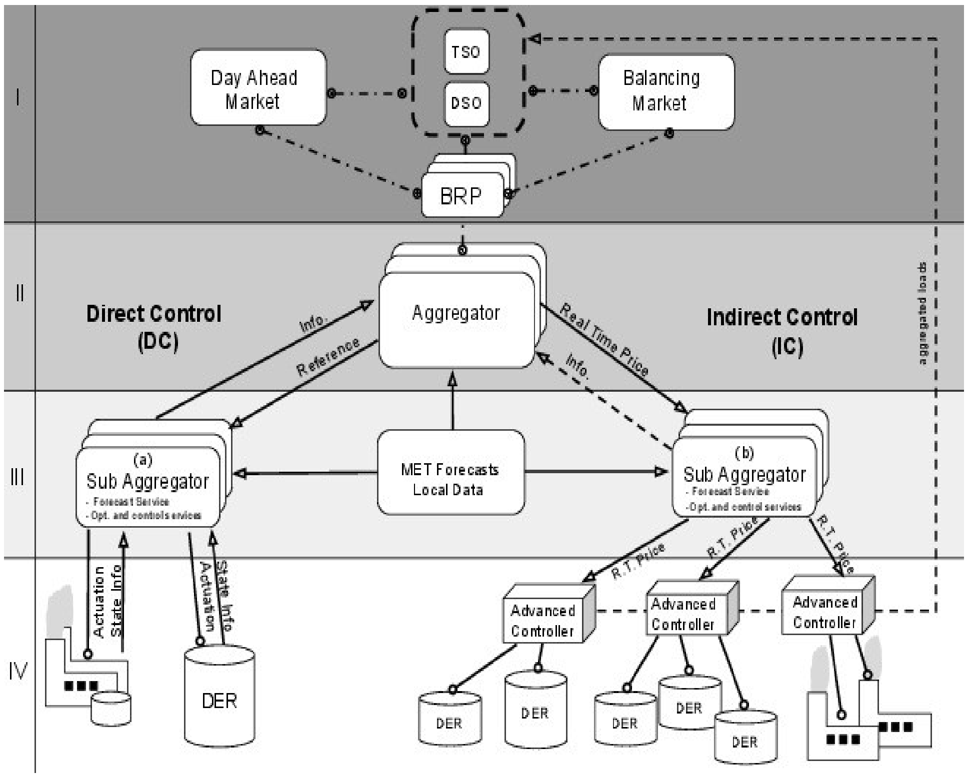
CITIES is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org .

Future Electric Energy System



CITIES
Centre for IT Intelligent Energy Systems

Control and Optimization



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

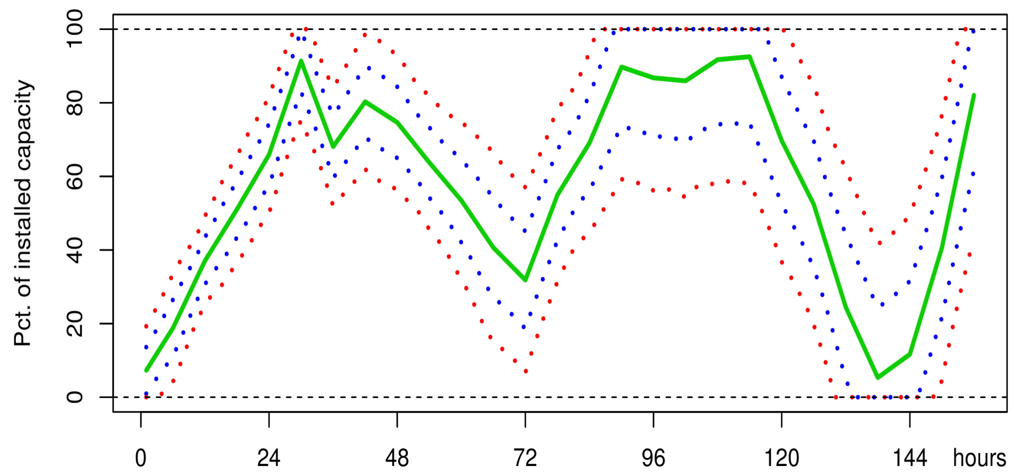
Table 3 – Difference between direct (DC) and indirect (IC) control.

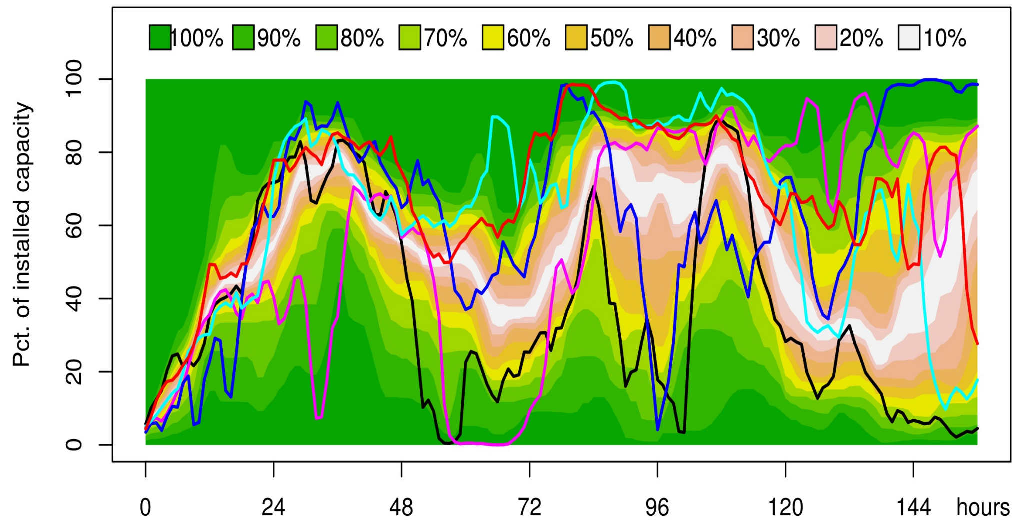
Level	Direct Control (DC)	Indirect Control (IC)
III	$\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k})$	$\min_{\hat{z},p} \sum_{k=0}^{N} \phi(\hat{z}_k, p_k)$ s.t. $\hat{z}_{k+1} = f(p_k)$
	$\downarrow_{u_1} \cdots \downarrow_{u_J} \quad \uparrow_{x_1} \cdots \uparrow_{x_J}$	
IV	s.t.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

Forecasting is Essential

Tools for Forecasting: (Prob. forecasts)

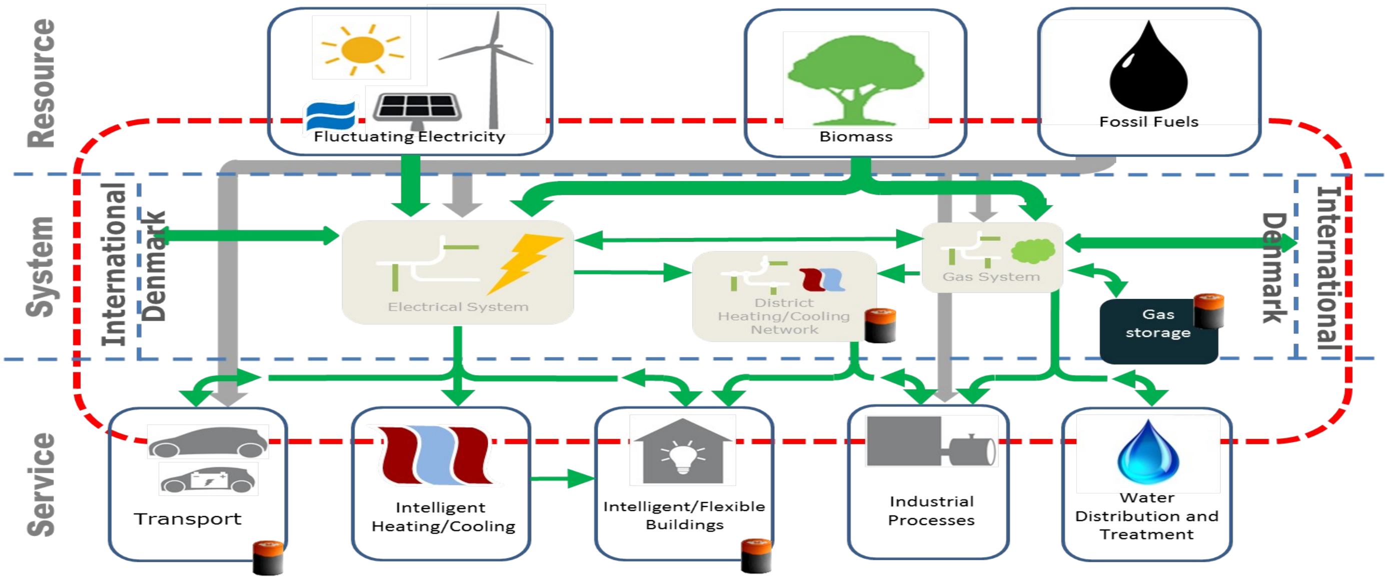
- **Power load**
- **Heat load**
- **Gas load**
- **Prices (power, etc)**
- **Wind power prod.**
- **Solar power prod.**
- **State variables (DER)**





CITIES
Centre for IT Intelligent Energy Systems

Virtual Storage by Energy Systems Integration



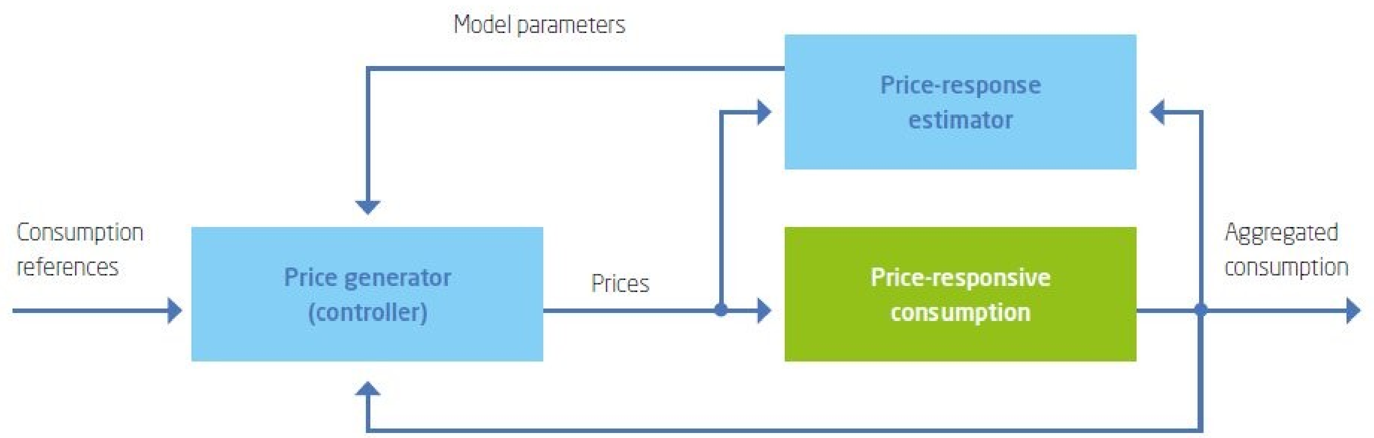
- **Denmark: 48 pct of power load by renewables (> 100 pct for some days)**
- **(Virtual) storage principles:**
  - Buildings (thermal mass) can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

Price-based Control of Power Load

CITIES
Centre for IT Intelligent Energy Systems

Price-based Control of Power Load

Figure 12 - Control of aggregated consumption based on a dynamic model (Price-response estimator) for the price-responsive consumption.

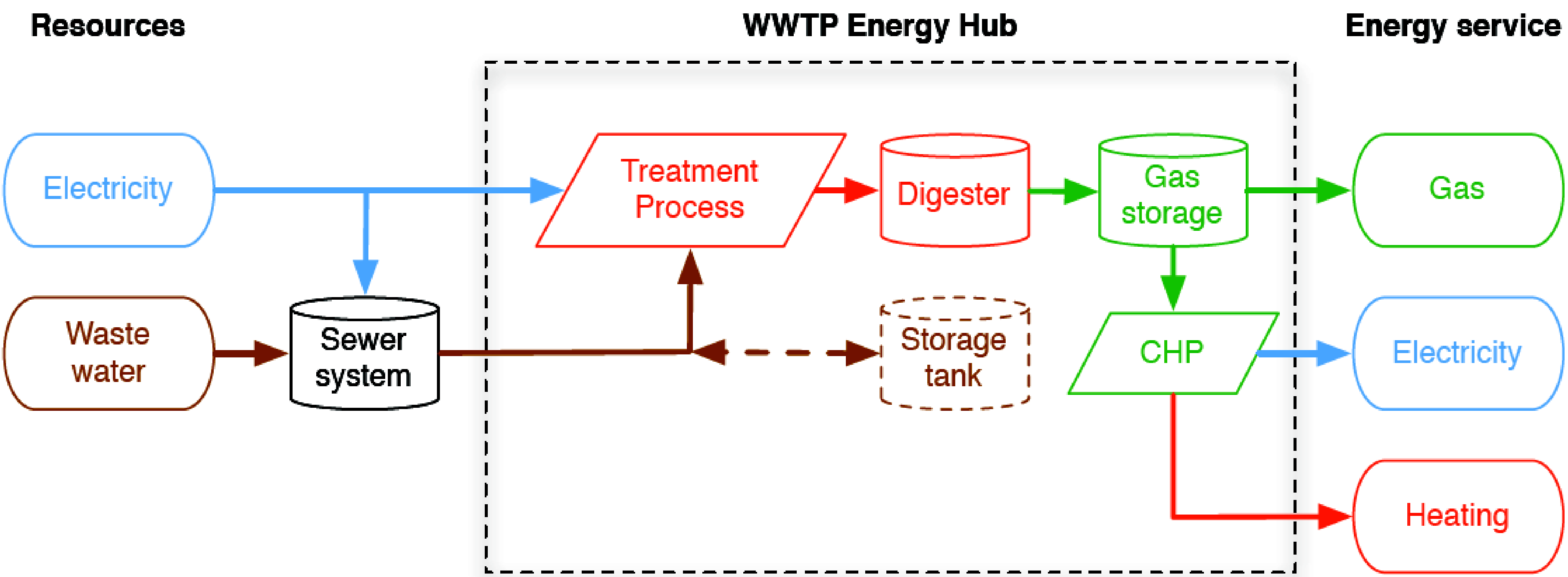


Case study

Control of Wastewater Treatment Plants

CITIES
Centre for IT Intelligent Energy Systems

Waste-2-Energy



CITIES
Centre for IT Intelligent Energy Systems

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

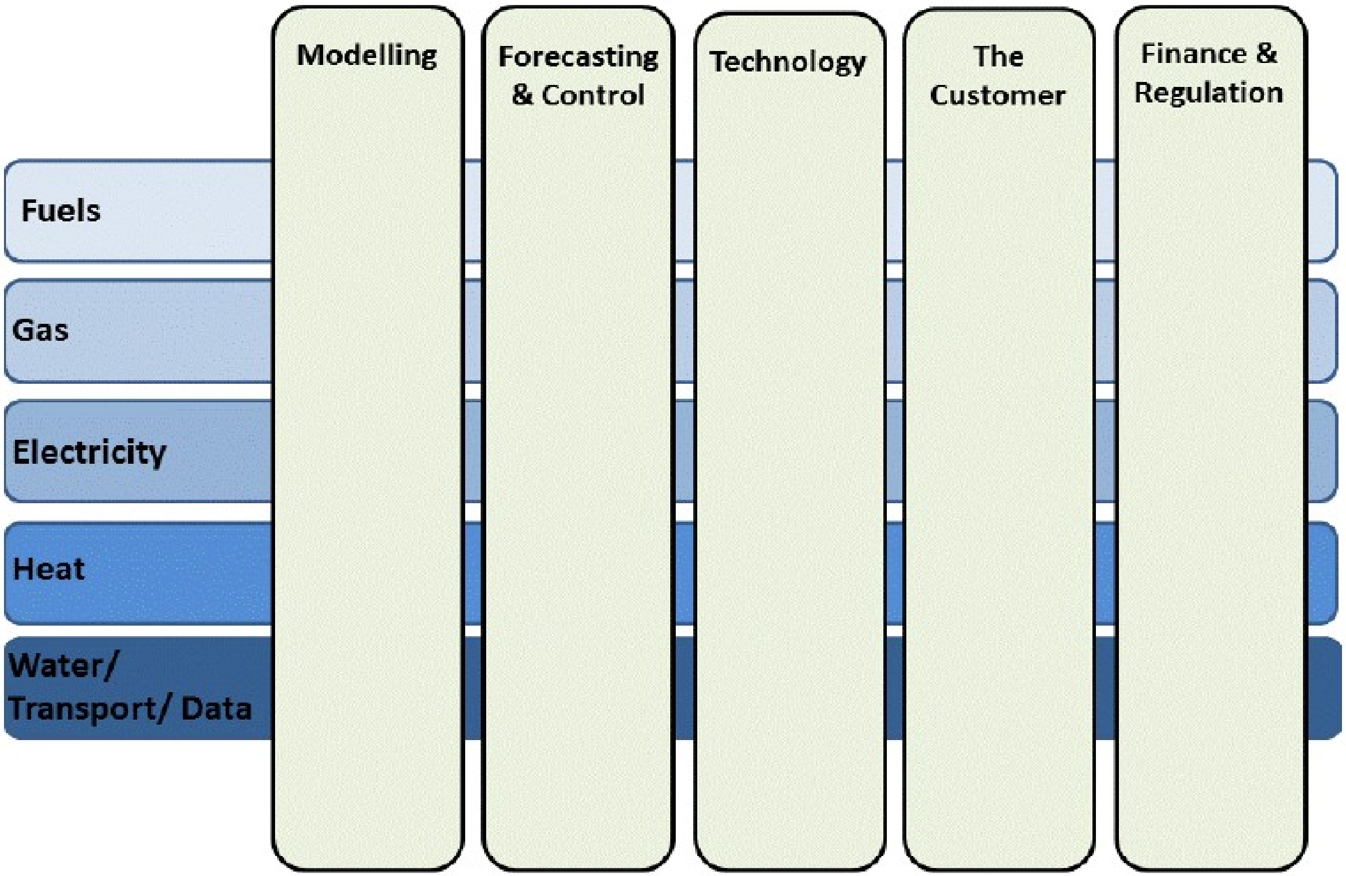
Minimize overflow risk

International Alliances on Energy Systems Integration

CITIES
Centre for IT Intelligent Energy Systems

Proposal (UCD, DTU, KU Leuven):

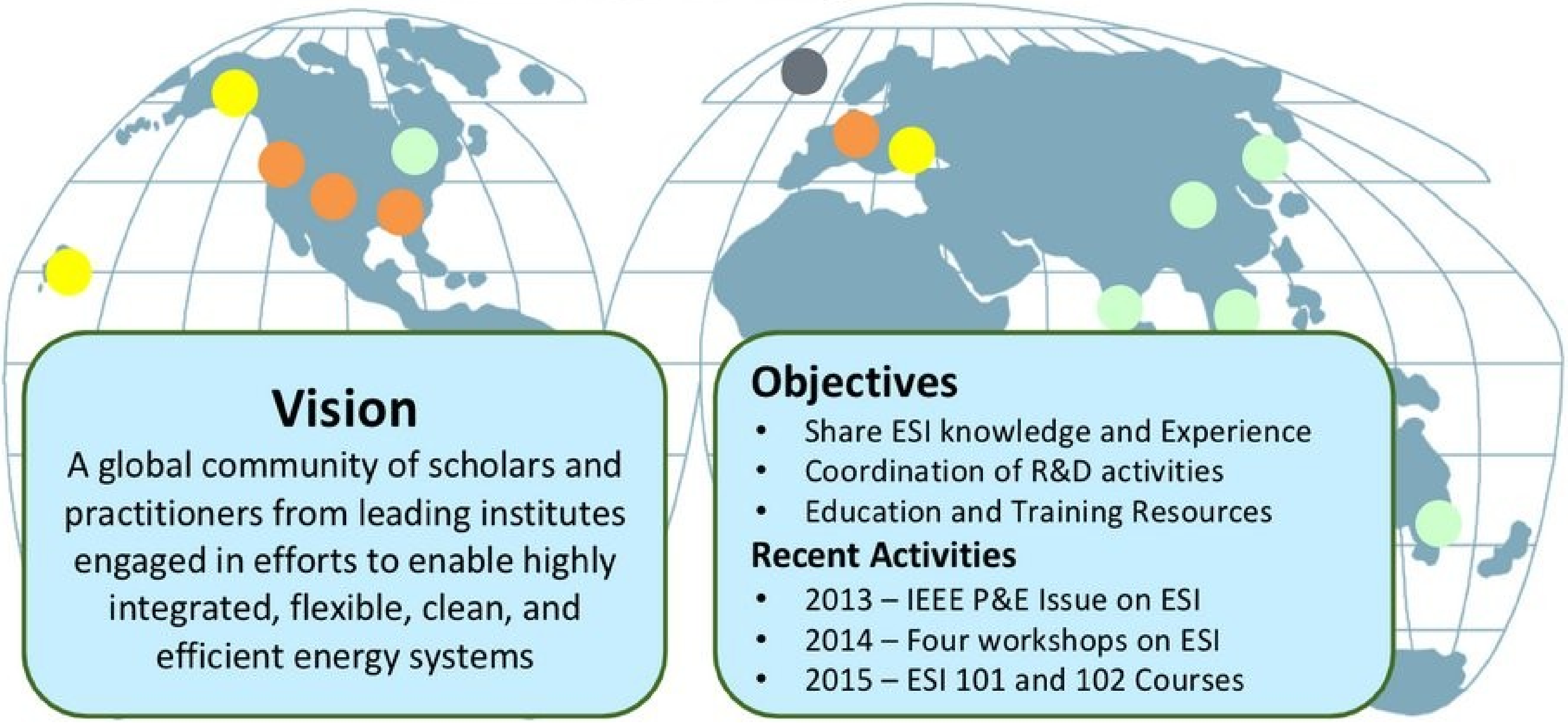
ESI Joint Program in EERA



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