CITIES
Center for IT-Intelligent Energy Systems in cities

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Quote by B. Obama at the Climate Summit 2014 in New York:

We are the **first generation** affected by climate changes, and we are the **last generation** able to do something about it!
Potentials and Challenges for renewable energy

Scenario: We want to cover the world's entire need for power using wind power.

How large an area should be covered by wind turbines?
Potentials and Challenges for renewable energy

**Scenario:** We want to cover the world's entire need for power using wind power.

How large an area should be covered by wind turbines?

**Conclusion:** Use intelligence ....

Calls for **IT / Big Data / Smart Energy/Cities Solutions/ Energy Systems Integration**
Wind integration in Denmark

<table>
<thead>
<tr>
<th>Power right now</th>
<th>Measured in MW:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central power stations</td>
<td>1.315</td>
</tr>
<tr>
<td>Local CHP plants</td>
<td>298</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>3.951</td>
</tr>
<tr>
<td>Solar cells</td>
<td>0</td>
</tr>
<tr>
<td>Net exchange eksport</td>
<td>2.096</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>3.469</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>164 g/kWh</td>
</tr>
</tbody>
</table>

LEGEND

- Jutland - Sweden
  Exports: 332 MW

- Jutland - Norway
  Exports: 1.530 MW

- Zealand - Sweden
  Exports: 1.026 MW

- Bornholm - Sweden
  Exports: 16 MW

- Jutland - Germany
  Imports: 473 MW

- Zealand - Germany
  Imports: 336 MW

The Great Belt
--- > 590 MW

Last updated 2. februar 2016 23:28
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 2015 more than 42 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power
Latest production data for Tyra: 6.061.111 kWh
Applicable for 15. februar 2014 11:00-12:00

Natural gas right now
Gas flow – kWh/h:
- Nybro entry: 5.882.672
- Ellund exit: 1.002.678
- Dragør exit: 1.405.760
- Energinet.dk Gas Storage: 824.732
- DONG Storage: 0
- Exit Zone: 4.776.523
- CO2 emission factor: 56.76 kg/GJ

Lille Torup gas storage facility Entry: 824.732 kWh/h
Calorific value: 12,150 kWh/m³

Nybro Entry: 5.882.672 kWh/h
Calorific value: 12,197 kWh/m³

Egtved: Calorific value: 12,213 kWh/m³
CO2 emissions factor: 56.76 kg/GJ

Dragør Exit: 1.405.760 kWh/h
Calorific value: 12,234 kWh/m³

Ellund Exit: 1.002.678 kWh/h
Calorific value: 12,228 kWh/m³

Stenlille gas storage facility: 0 kWh/h
Calorific value: 12,022 kWh/m³

Last updated 15. februar 2014 12:31
Gas system is very important ... (Storage capacity approx. 40 Tesla Powerwalls in each house)

From large central plants to Combined Heat and Power (CHP) production

1980

From a few big power plants to many small combined heat and power plants – however most of them based on coal

Today

DK has enough excess heat to cover the entire need for heating .... but ...

Boston Climate Bridge – Women Leading Change
CHP and Integrated Energy Systems
(Paradigmatic example - Denmark)

Gas Turbine

Steam Turbine

Electricity

District heating

Heat tank

Waste incinerators,
Supermarket cooling,
Industrial processes
Flexibility – Ringkøbing CHP

Ringkøbing District Heating - 28-05-2016 23:36:00

Solar Collector
Solar Collector
Gas Engine
Gas Engine
Gas turbine
Gas turbine

Heat Storage 2.2 MW
Heat Storage 2.2 MW

Solar Radiation: 2 W/m²
Outdoor Temperature: 13°C

Sold Electricity: 0.0 MW

Forward temperature: 62 °C
District Heating: 5.8 MW
Return temperature: 38 °C

3.6 MW
316 m³/h

0.0 MW
0.0 MW

82.0 MWh

Ringkøbing Fjernvarmeværk

Boston Climate Bridge – Women Leading Change
Flexibility – Ringkøbing CHP

Ringkøbing District Heating, Friday, 2016-01-01 to Friday, 2016-01-08
What has since been achieved: De-coupling of consumption and GDP growth

Danish Climate and Energy Policy / Goals

- **2020**: 50% of electricity from wind power, and 35% of total energy consumption from renewable sources
- **2035**: 100% of electricity and heating from renewable sources
- **2050**: 100% of all (electricity, heating, transport, industry) from renewable sources
CITIES

Assumptions, Goals and Methods
The **central hypothesis of ESI** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

**Intelligent integration** will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.
CITIES – Research Challenges

To establish methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales
CITIES – Concept Challenges

Energy Systems Integration using data and IT solutions leading to models and methods for planning and operation of future electric energy systems.
Denmark (2014): Approx 42 pct of power load by renewables (> 100 pct at some days in January)

(Virtual) storage principles:
- Buildings 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
Smart-Energy OS

Day Ahead Market

Transmission System Operator (TSO)

Distribution System Operator (DSO)

Balance Responsible Party

DIRECT CONTROL (DC) Individual consumption schedules

Aggregator

Meteorological forecasts

Local data

Real-time price

Reference

INDIRECT CONTROL (IC) Price signals

Sub Aggregator A Forecast services

Advanced controller

Industrial processes

Water distribution & treatment

Intelligent heating/cooling

Intelligent buildings

Solar thermal

Advanced controller

Industrial processes

CHP plant

Aggregated loads

Intraday market
How to reach a fossil-free society

100% Renewables

Multiple supply strings

Dynamic tariffs

Tax rules reflecting market price

Intelligent consumption
Demand response management

Biomass

Forecasting of Wind and Solar Power
Case study

Control of Wastewater Treatment Plants
Waste-2-Energy

Resources

Electricity

Waste water

Sewer system

WWTP Energy Hub

Treatment Process

Digester

Gas storage

Storage tank

Energy service

Gas

Electricity

Heating
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

Sewer system → WWTP

Elspot price forecast → STAR

- Sensor filtering and time delay
- CTSM-R Model parameter estimation
- Closed loop prediction

R
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 on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R. The software is available on GitHub.
Case study

Use of Heat from Supermarket Cooling in DH Systems
Using Heat from Supermarket Cooling in the District Heating System

SuperBrugsen in Høruphav

- Area: 1000 m² from 2010
- Compressors: 5 MT (1 VS), 4 LT
- Cooling Capacity: 160 kW

Heating:
- Sanitary water (1800 l tank (65 °C ))
- Floor heating/low temp coils (35 °C )
- District heating production
Using Heat from Supermarket Cooling in the District Heating System

- SuperBrugsen gets paid for energy they would have otherwise have paid for to get removed
- Corresponds to the total consumption of 15-20 households
- Payback time for SuperBrugsen is 1-2 years
- Payback time for DH system is 3-4 years
- This is a small supermarket. Business case even better for large supermarkets
**Virtual Storage or Flexibility Characteristics**

- Supermarket refrigeration can provide storage 0.5-2 hours ahead
- Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
- Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
- District heating/cooling systems can provide storage up to 1-3 days ahead
- Gas systems can provide seasonal storage
Energy Flexibility
Some Demo Projects in CITIES

- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ....)
- CHP (Dong Energy, FjernvarmeFyn, HOFOR, NEAS, ..)
- Industrial production (DI, ..)
- VE (charging) (Eurisco, ED, ..)
UCD, DTU, KU: ESI Joint Program ESI European Research (EERA)
Addressing energy challenges through global collaboration

**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

**Activities 2014**
- Feb 18-19 Workshop (Washington)
- May 28-29 Workshop (Copenhagen)
- July 21 – 25, ESI 101 (Denver)
- Nov 17th Workshop (Kyoto)

**Activities 2015**
- Dublin, Denver, Brussels, Seoul
Discussion

- Intelligent Energy Systems Integration can provide virtual storage solutions (... less need for physical storage)
- District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)
- We have enough waste heat to cover the entire need for heating (but ... !)
- Gas systems can provide seasonal virtual storage solutions (but ... !)
- We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important
- We see large problems with the tax and tariff structures. Coupling to prices for carbon capture could be advantageous.
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)
Discussion (2)

- Smart Cities is a part of a Smart Society
- Within CITIES a number of solutions have been developed
- A huge potential in the use of smart meter data
- It is our impression that by intelligent energy systems integration we could rather easily obtain a fossil-free society, however ....
- We need stronger decision makers ...

Thanks for your attention!
Use of Meter Data

- Reliable Energy Signature.
- Energy Labelling
- Time Constants (eg for night set-back)

Proposals for Energy Savings:
- Replace the windows?
- Put more insulation on the roof?
- Is the house too untight?
- ......

- Optimized Control
- Integration of Solar and Wind Power using DSM