Energy Systems Integration Research Challenges

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Quote by B. Obama:
(U.N. Climate Change Summit,
New York, Sept. 2014)

We are the *first generation*
affected by climate changes,
and we are the *last generation*
able to do something about it!
**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 Solutions/ Energy Systems Integration
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 December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load
Wind integration in Denmark

Power right now
Measured in MW:
- Central power stations: 1,575
- Local CHP plants: 401
- Wind turbines: 4,088
- Solar cells: 113
- Net exchange export: 1,845
- Electricity consumption: 4,331
- CO2 emissions: 179 g/kWh

Legend:
- Jutland - Sweden: Exports: 728 MW
- Jutland - Norway: Exports: 953 MW
- Zealand - Sweden: Exports: 1,048 MW
- Bornholm - Sweden: Exports: 2 MW
- Jutland - Germany: Imports: 284 MW
- Zealand - Germany: Imports: 601 MW
- The Great Belt: 590 MW

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From large central plants to Combined-heat and power production

1980

Today

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

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.
ESI – Research Challenges

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

Energy Systems Integration using data and IT solutions leading to models and methods for planning and operation of future electric energy systems.
Example: Storage by Energy Systems Integration

Denmark (2014): 48 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
Case study

Control of Power Consumption (DSM)
Data from BPA

Olympic Pensinsula project

- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption
Aggregation (over 20 houses)
Non-parametric Response on Price Step Change

Model inputs: price, minute of day, outside temperature/dewpoint, sun irradiance

Olympic Peninsula

![Graph showing consumption step response over 20 hours with a marked 5-hour interval](image)
Control of Energy Consumption

[Diagram showing the control process with boxes for model parameters, price-response estimator, price generator, price-responsive consumption, and consumption references.]

Workshop at Lithuanian Energy Institute, June 2015
Control performance

Considerable **reduction in peak consumption**
Mean daily consumption shift
Control and Optimization
Control and Optim. Challenges

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'

Forecasting is very important

Type of forecasts:
- Point forecasts
- Conditional mean and covariances
- Conditional quantiles
- Conditional scenarios
- Conditional densities
- Stochastic differential equations
How can we make a difference?
Proposal (UCD, DTU, KU Leuven): ESI Joint Program as a part of 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, Hawaii, Brussels, Australia
Energy Systems Integration can provide virtual and lossless storage solutions (so maybe we should put less focus on physical storage solutions)

Energy Systems Integration might be able to solve many of the problems Europe now is trying to solve by Super Grids (some of these huge investments might not be needed)

Europe should put less focus on super-grids - I assume that ESI can solve a major part of the issues (the planned investments are huge - and maybe we don't need them)

Focus on zero emission buildings - and less on zero energy buildings (the same holds supermarkets, wastewater treatment plants, etc.)

District heating (or cooling) provide virtual storage on the essential time scale (up to a few days)

We see a large potential in Demand Side Management. Automatic solutions and end-user focus is important

We see a large potential in coupling cooling (eg. for comfort) and heating systems using DH networks

We see large problems with the tax and tariff structures in many countries (eg Denmark). 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)