Spinning Reserve Determination in a Power System with Significant Wind Power Generation
-CFA meeting-

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Outline

- **Electricity Market Background**
  - ➤ **A Nordic Elspot market area**
  - ➤ **Power imbalance: cause and consequence**
  - ➤ **Reserve: when and where to trade**

- **Project Objective**

- **Project Methods**

- **Mathematical Models**

Nordic Elspot Market Areas

Norway: 5 areas
Sweden: 4 areas
Denmark: 2 areas
Finland: 1 area
Estonia: 1 area

Elspot volumes

	Buy	Sell
NO1	4 946,0	2 465,3
NO2	4 419,7	7 090,7
NO3	2 493,2	1 293,2
NO4	2 121,3	3 171,3
NO5	1 761,1	911,1
DK1	2 006,1	2 720,7
DK2	1 676,9	1 834,5
SE1	1 295,1	3 548,3
SE2	1 681,7	3 953,1
SE3	11 244,3	10 310,4
SE4	3 263,1	751,4
FI	6 475,8	5 699,3
EE	1 161,2	1 249,5
ELE	466,3	13,0
LT	1 024,3	1 024,3

System price: **49.26**
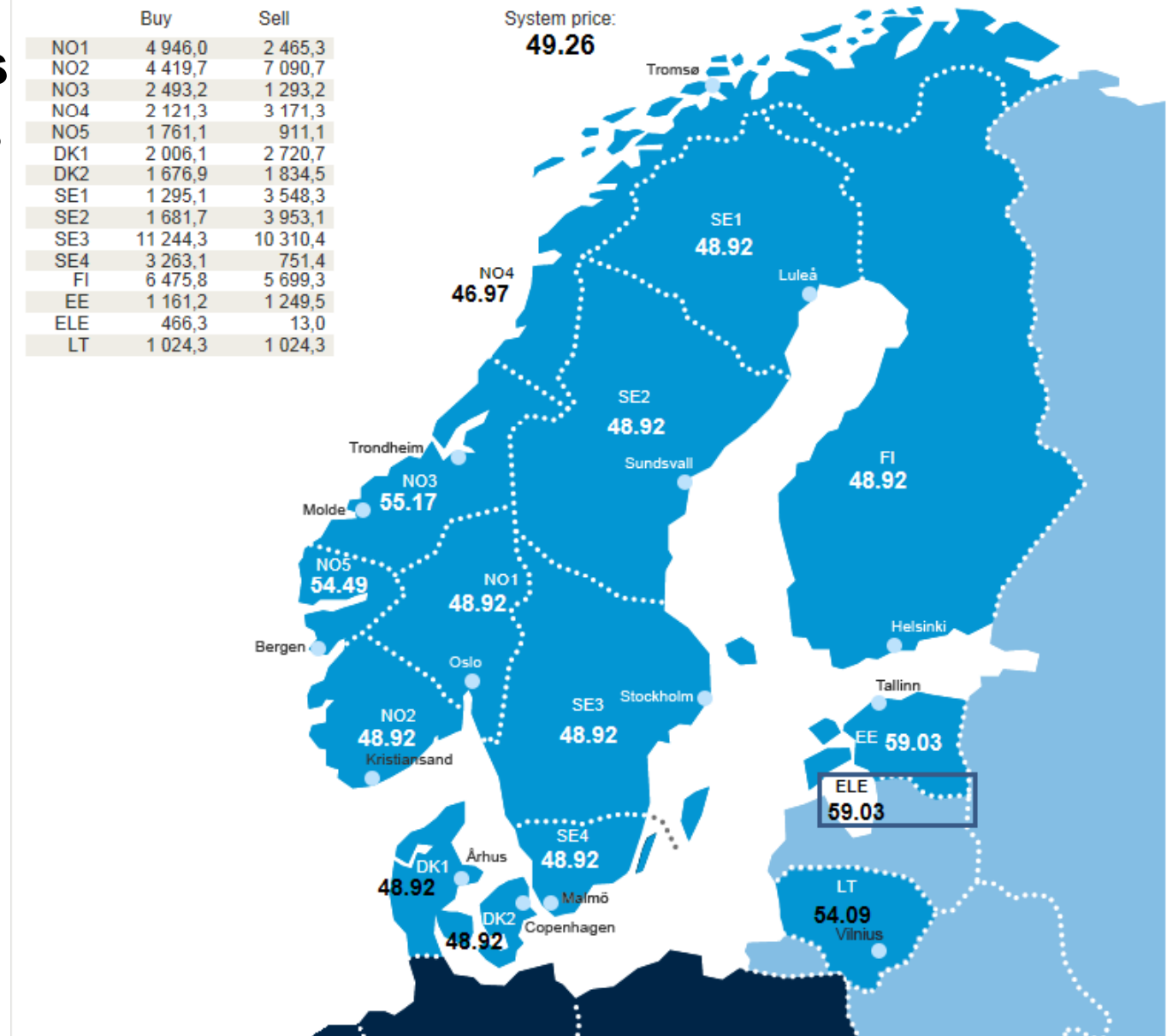
Cause of Power Imbalance

Generator failure

Demand forecast error

Wind power forecast error

Consequence of power Imbalance

Let's isolate DK1 from the rest of the world!

Generation
Reserve

Demand
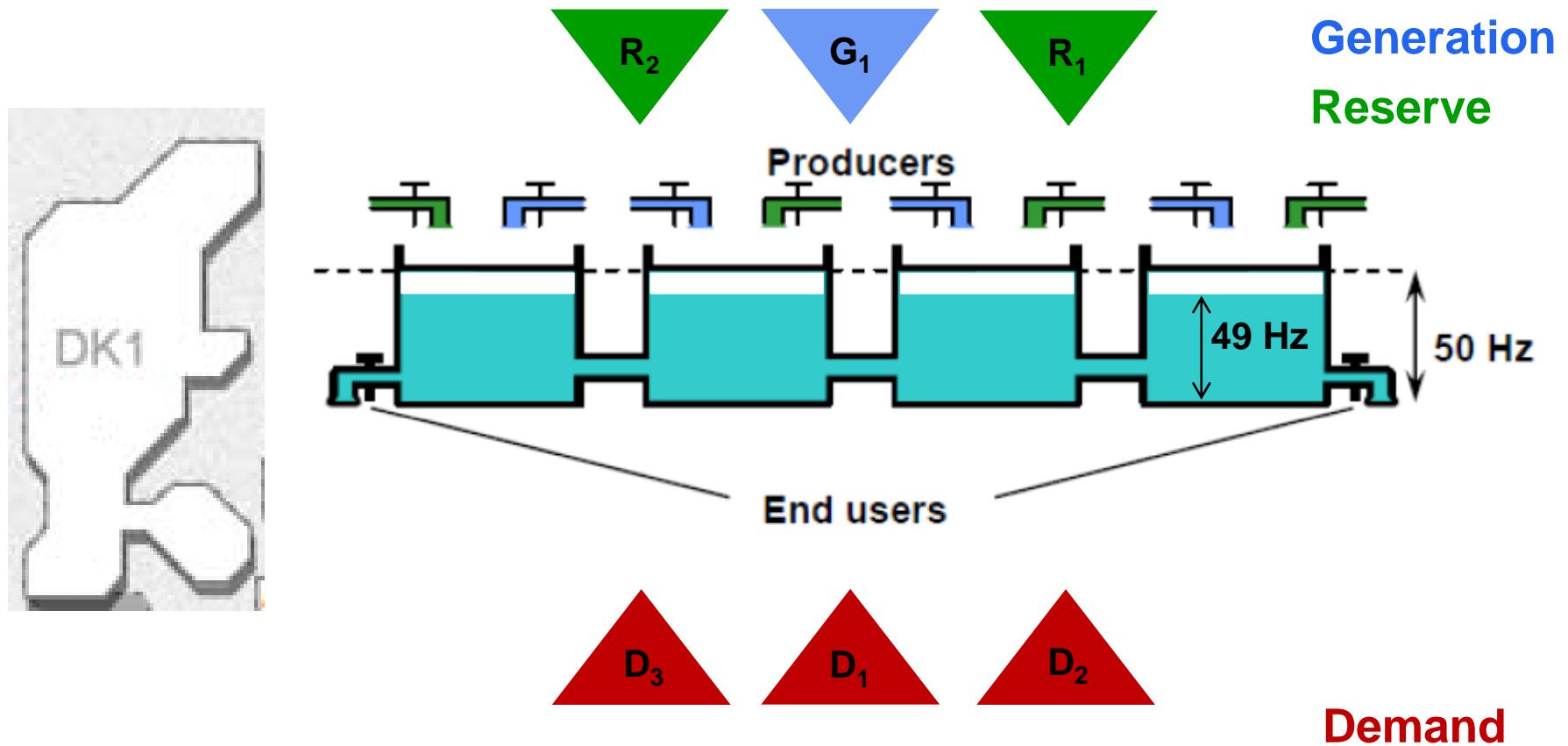
Generator Capacity: Energy & Reserve

Maximum

Reserve

Minimum

Energy

0 MW
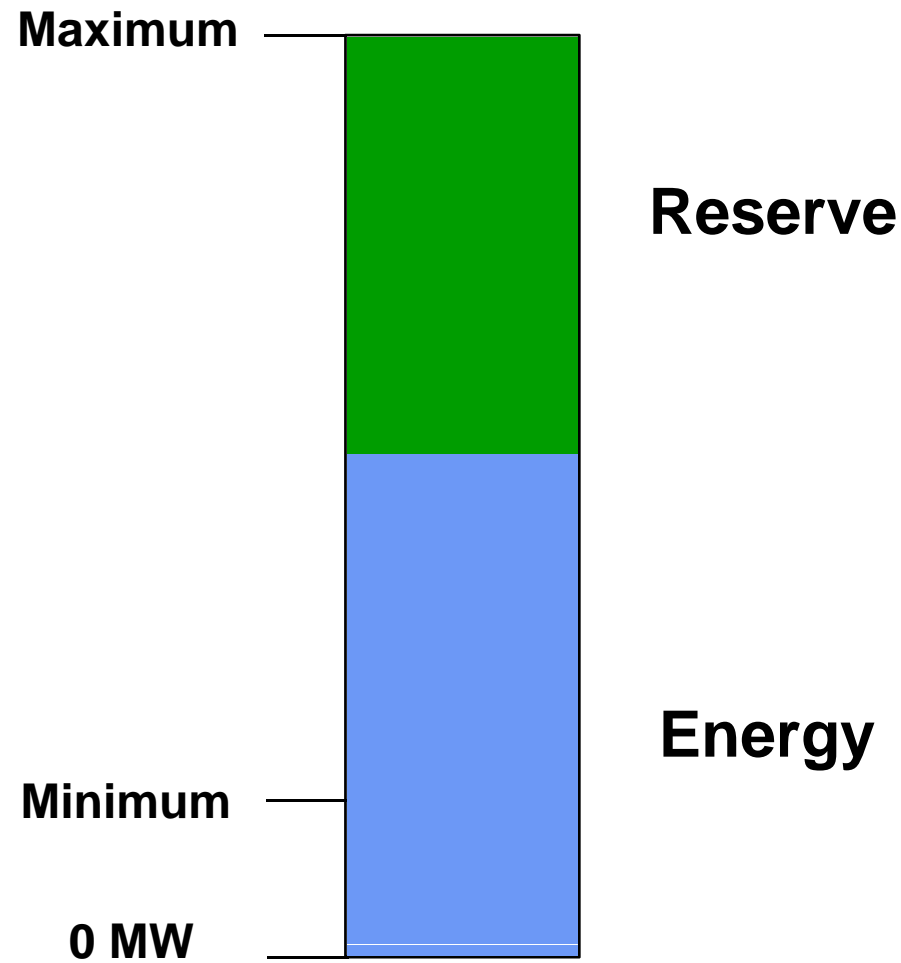
When to Trade Energy and Reserve

Thursday   **Friday**

| Trade Reserve Capacity closes at 09:30 | Trade Energy Nord Pool's Elspot Market closes at 12:00 | Voluntary bids to Regulating Market closes *t* - 45 min | TSO Activates Needed Reserve |

Hour of operation

Thursday 00:00   09:30   12:00   00:15   01:00   02:00

Day of operation

Day-Ahead Trade   Real-Time Balancing   Settlement

Slide modified based on presentation by Energinet.dk   **7 (15)**

Project Objective

1. How much <u>reserve capacity/volumn</u> should be procured by the TSO day-ahead to secure the power balance in the next day?

2. How wind power and load <u>forecasting error</u> affects the requirement of system reserve?

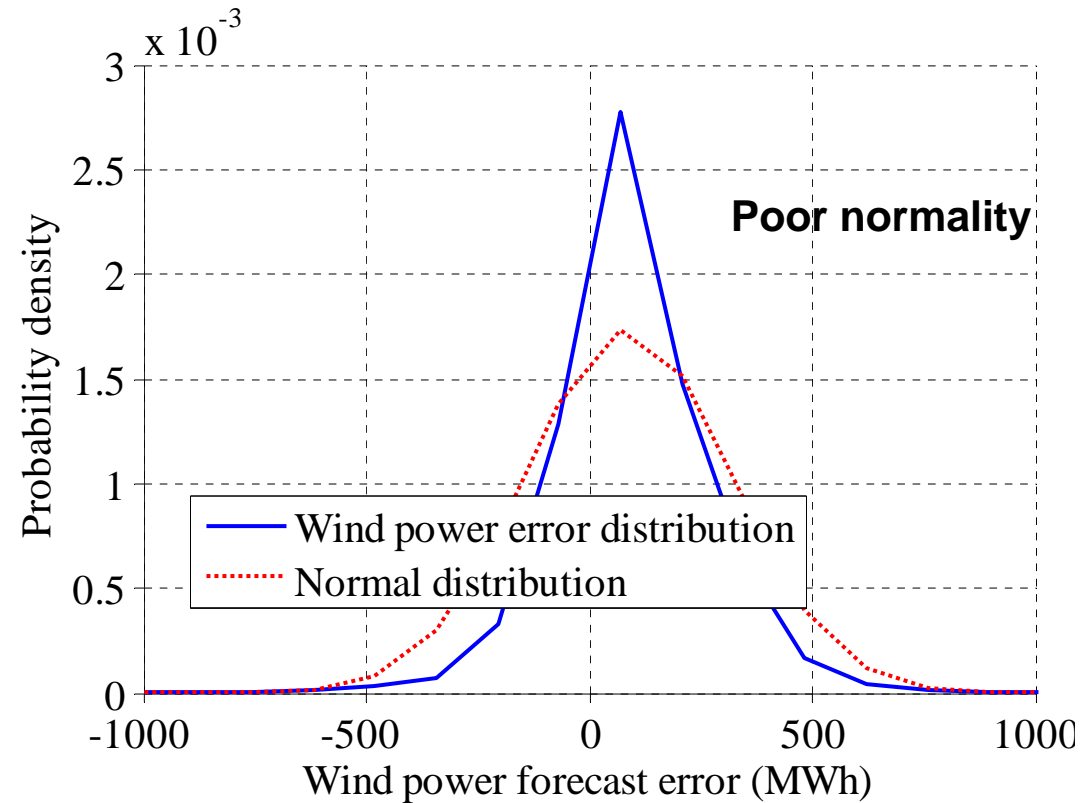3. How much can <u>energy storage</u> contribute to the reduction of power imbalance?

Methods

- **Electricity market theory**

- **Power system analysis**

- **Stasticial analysis**

- **Scenario generation and reduction**
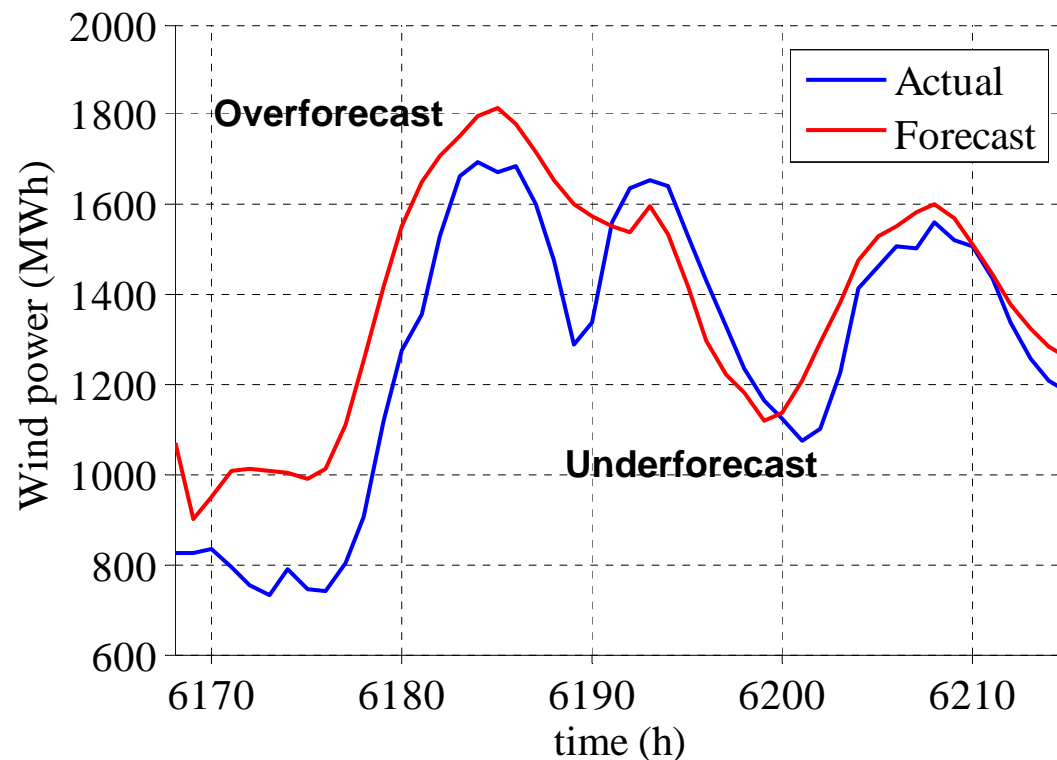
- **Stochastic optimization**

Probability Distribution of Load Forecast Error

$$R^D = \sigma(\Delta D)\Phi^{-1}(1-\alpha)$$
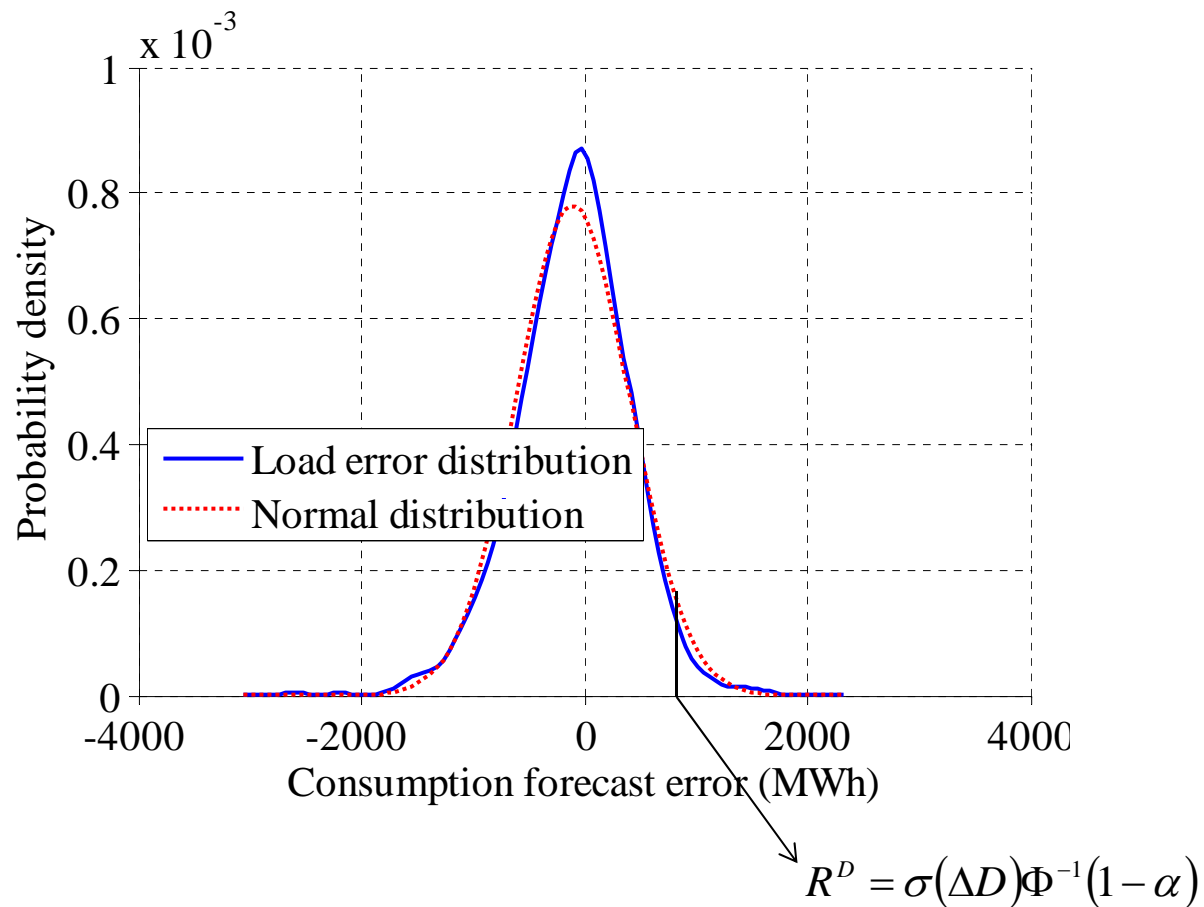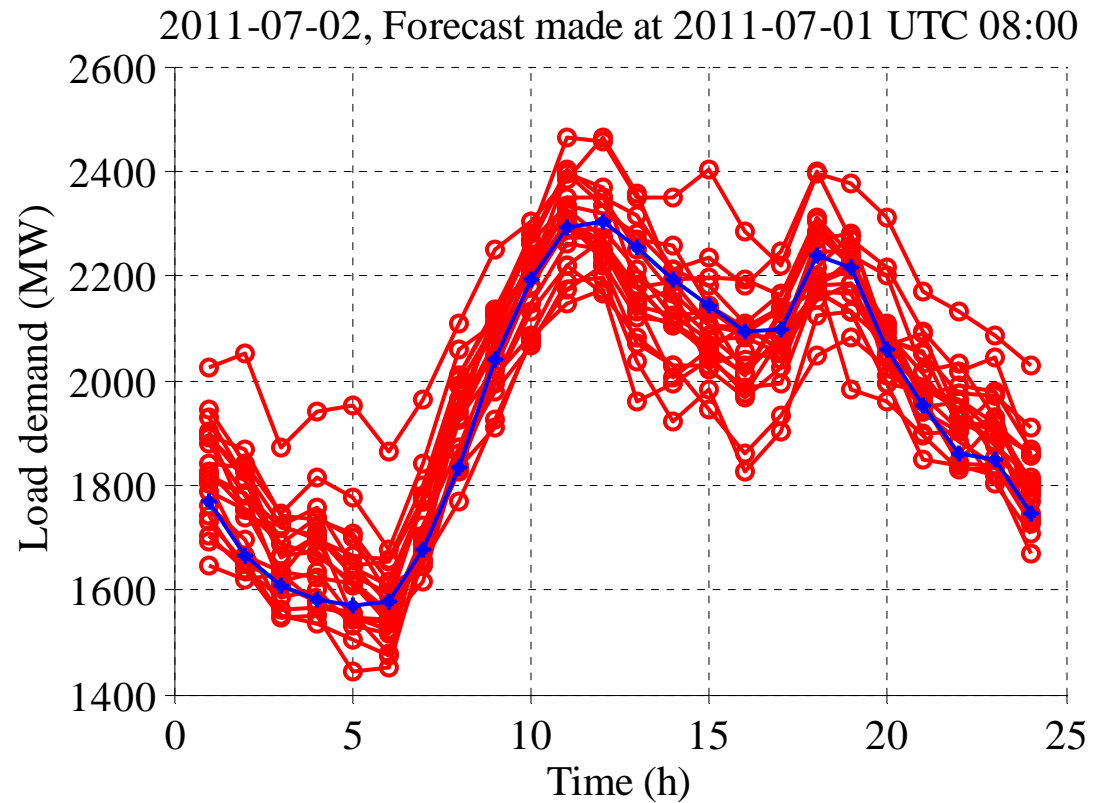
Probability Distribution of Wind Power Forecast Error

Temporal Correlation of Wind Power Forecast Error

**Temporal correlation
(Day-ahead forecast)**

Scenarios of Gross Consump.

2011-07-02, Forecast made at 2011-07-01 UTC 08:00

Scenarios of Wind Production

2011-07-02, Forecast made at 2011-07-01 UTC 08:00
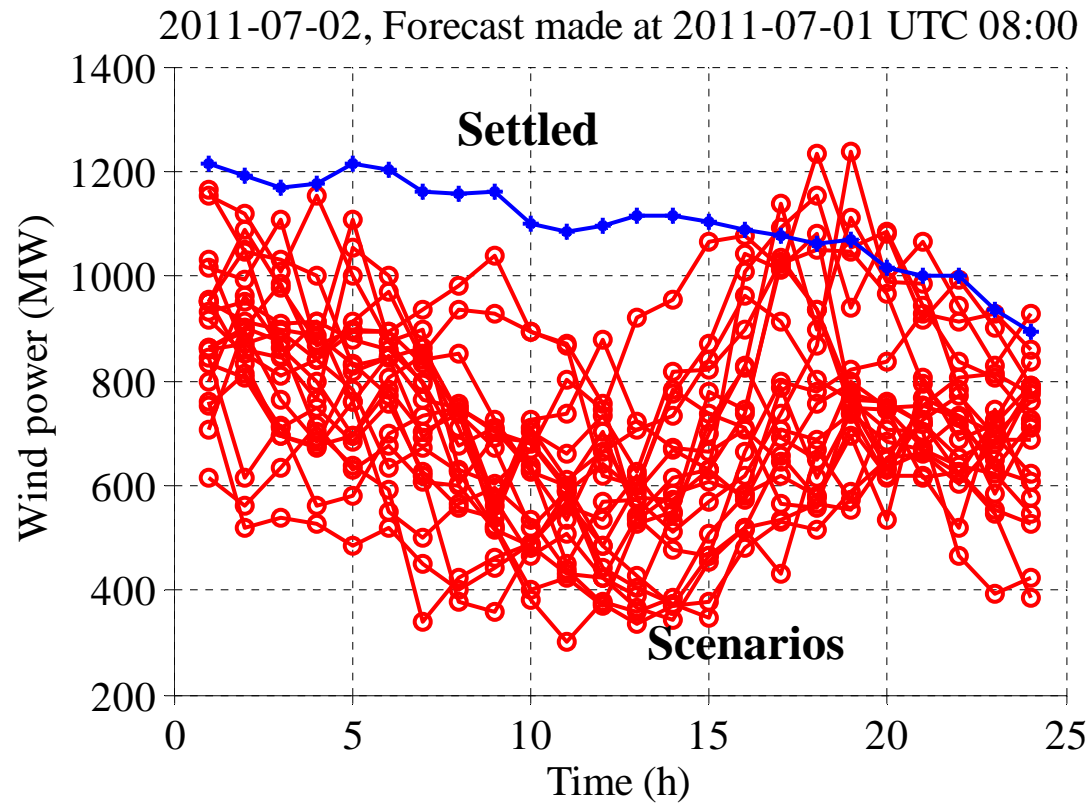
The Bi-Level Optimization Model