EKC^2 + ACCESS *Smart Grids* Workshop
Control and Pricing in Power Systems

Pricing in markets with large amounts of variable power.

Stockholm, 24 May, 2011

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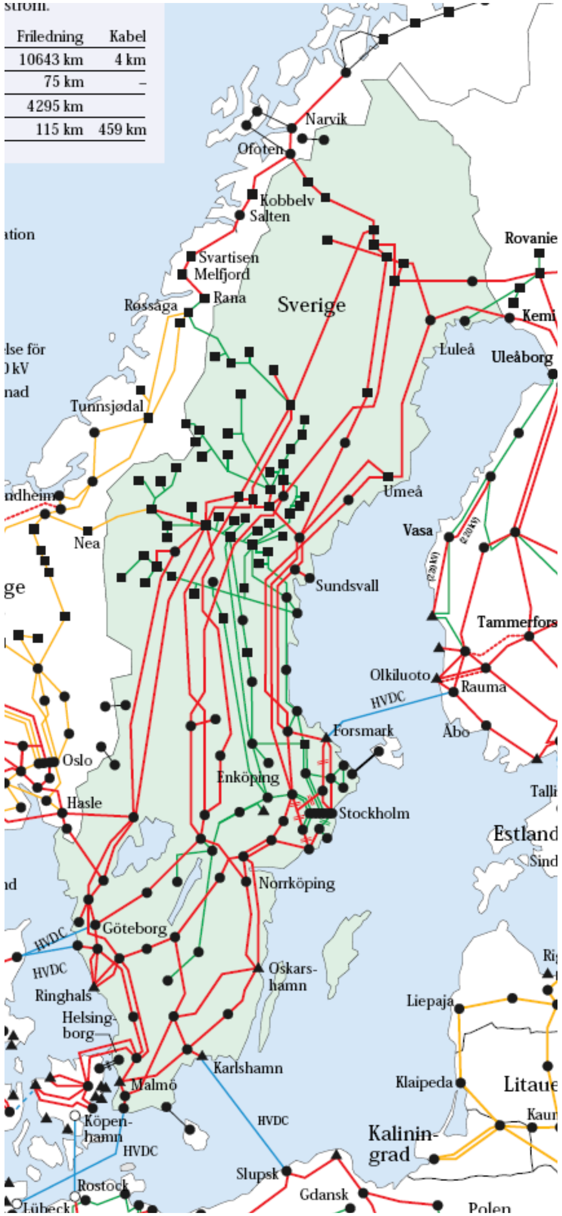
Swedish electricity market

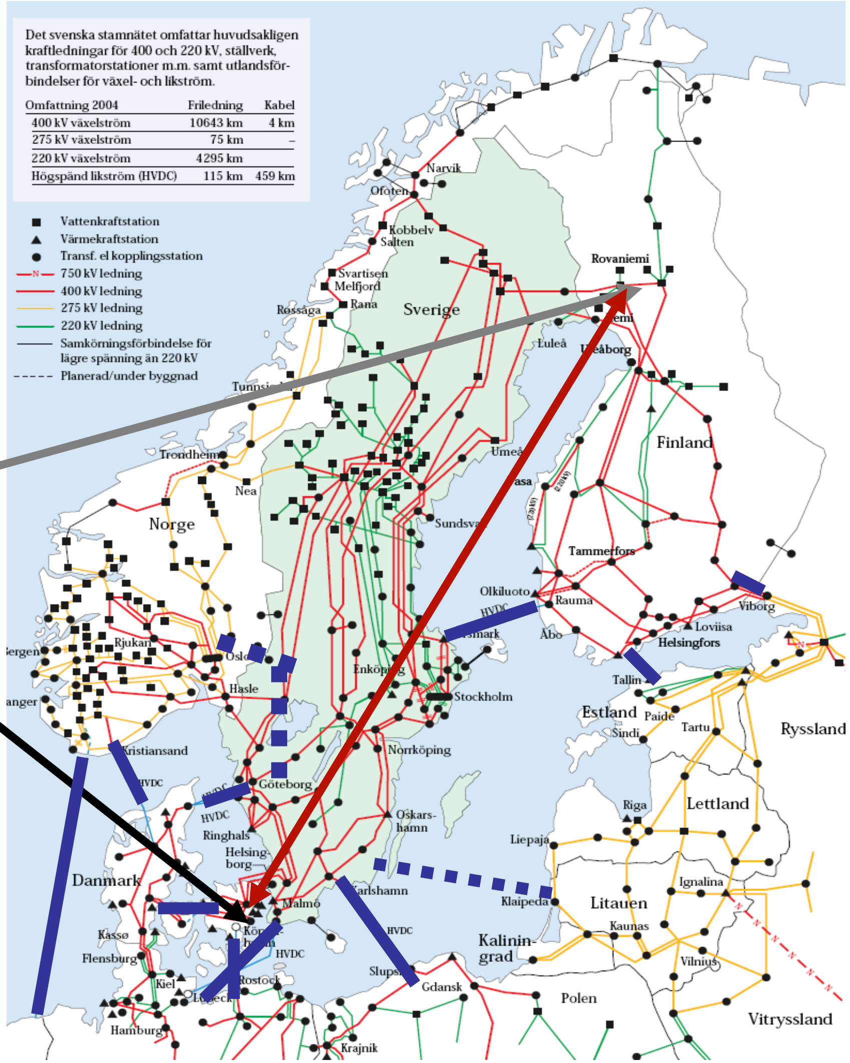
- I consume ≈ **6500 kWh/year**
- The consumption is **measured per hour**, but the application is kWh/month
- I get one invoice from the **grid owner**
- I get one invoice from **the retailer**. I can select among >100 retailers with different prices and contracts



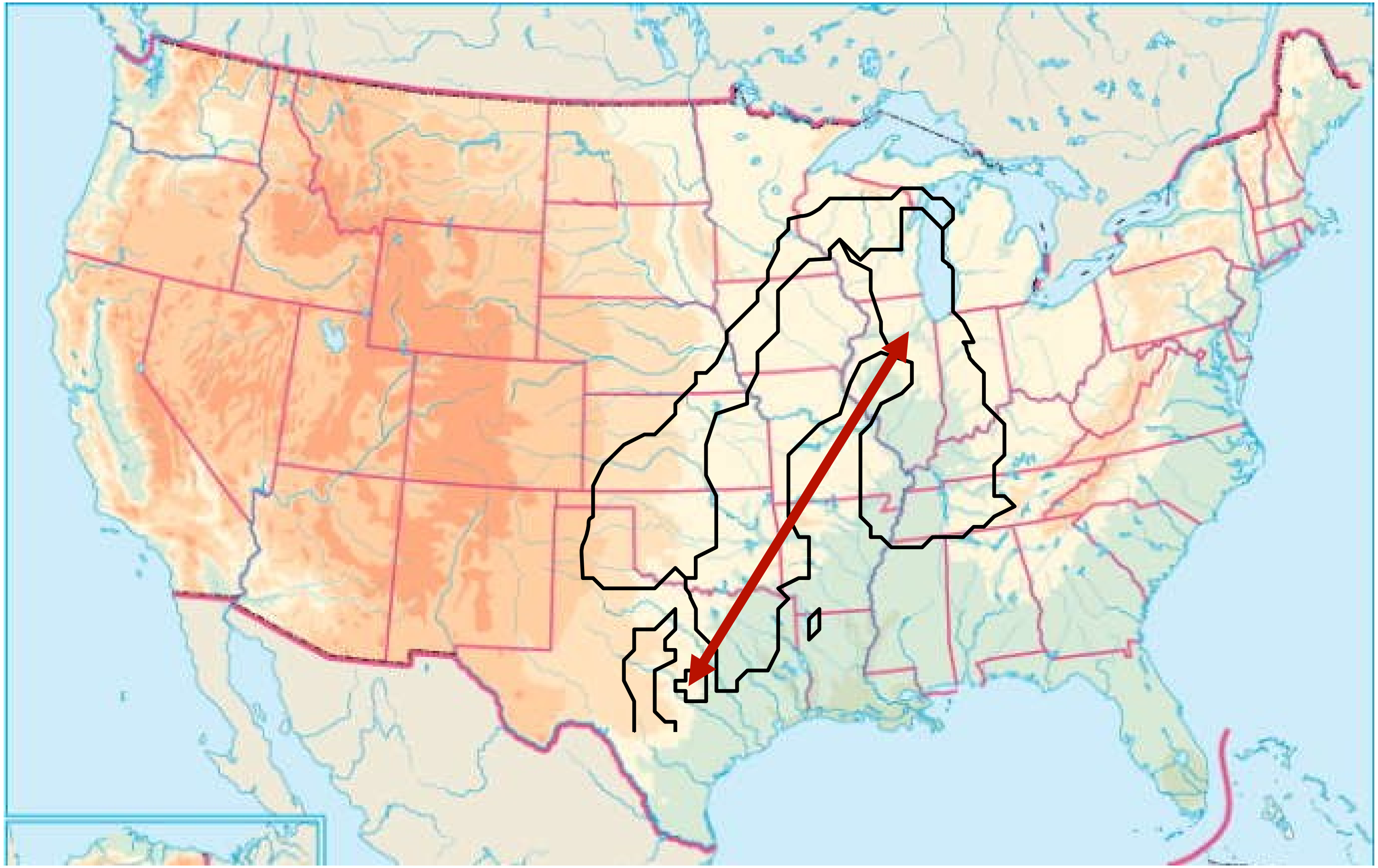
HVDC and Nordic Balancing

Nordic regulating market:

- No AGC (except Dk-W)!
- Assume that wind power decreases in Denmark with 100 MW
- The bids to the regulating market (tertiary control – up-regulation in 15 minutes) are coordinated in the Nordic system
- If an up-regulating bid from northern Finland is the cheapest and transmission limits are not violated, then this one is used!
- Distance: ~1400 km
- HVDC – in operation
- HVDC - planned



Nordic countries in USA



Distributed decision-making and control in complex systems:

1. Variable power sources
2. Pricing in power systems
3. Pricing with variable power sources
4. Impact on operation, inter-area trading and investments
5. Competition between DSM, transmission and production
6. Production capacity challenge
7. Transmission capacity challenge

Aim of a power system:

1. Supply consumers with electricity when they want

   = keeping the continuous balance between production and consumption

   (deregulated ➔ competition)

2. Keep the voltage for the consumers

   (regulated monopolies)

unbundling

Power = current · voltage

Renewable energy systems

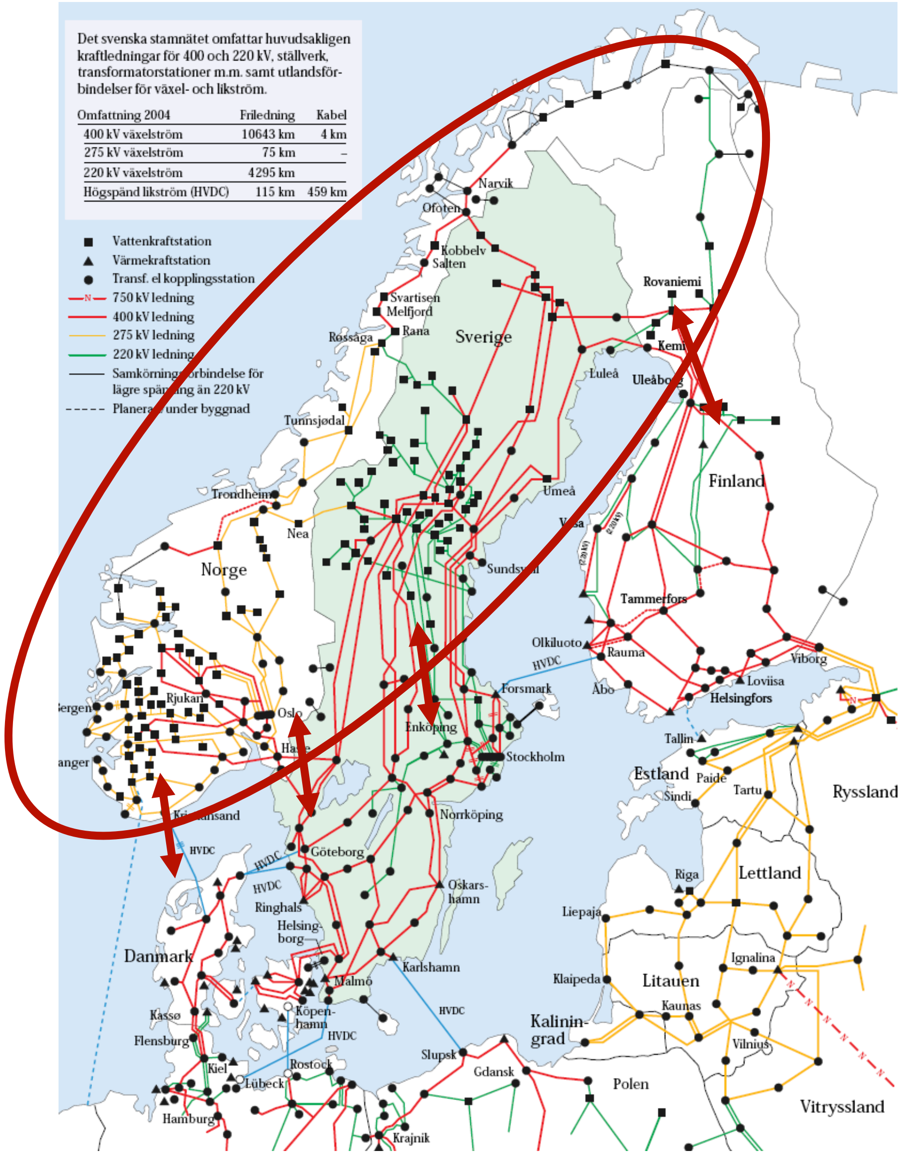
- Energy is ”produced” where the resource is
- The energy has to be transported to consumption center
- The energy inflow varies, which requires storage and/or flexible system solutions

- This is valid for hydro power, **wind power**, solar power

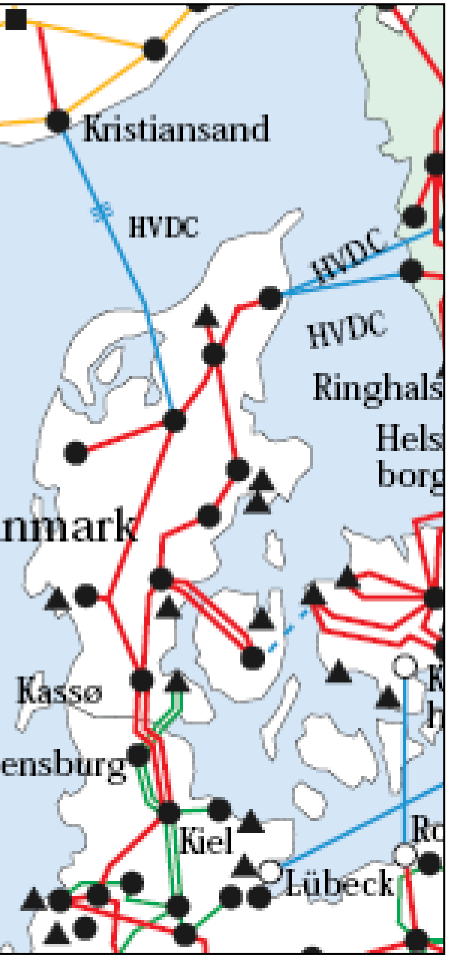
Example

- Nordic hydro inflow can vary 86 TWh between different years (1996, 2001)
- Transport from north Sweden to south Sweden
- Energy **balancing** with thermal power in Da+Fi+Ge+EE+Pl+NL

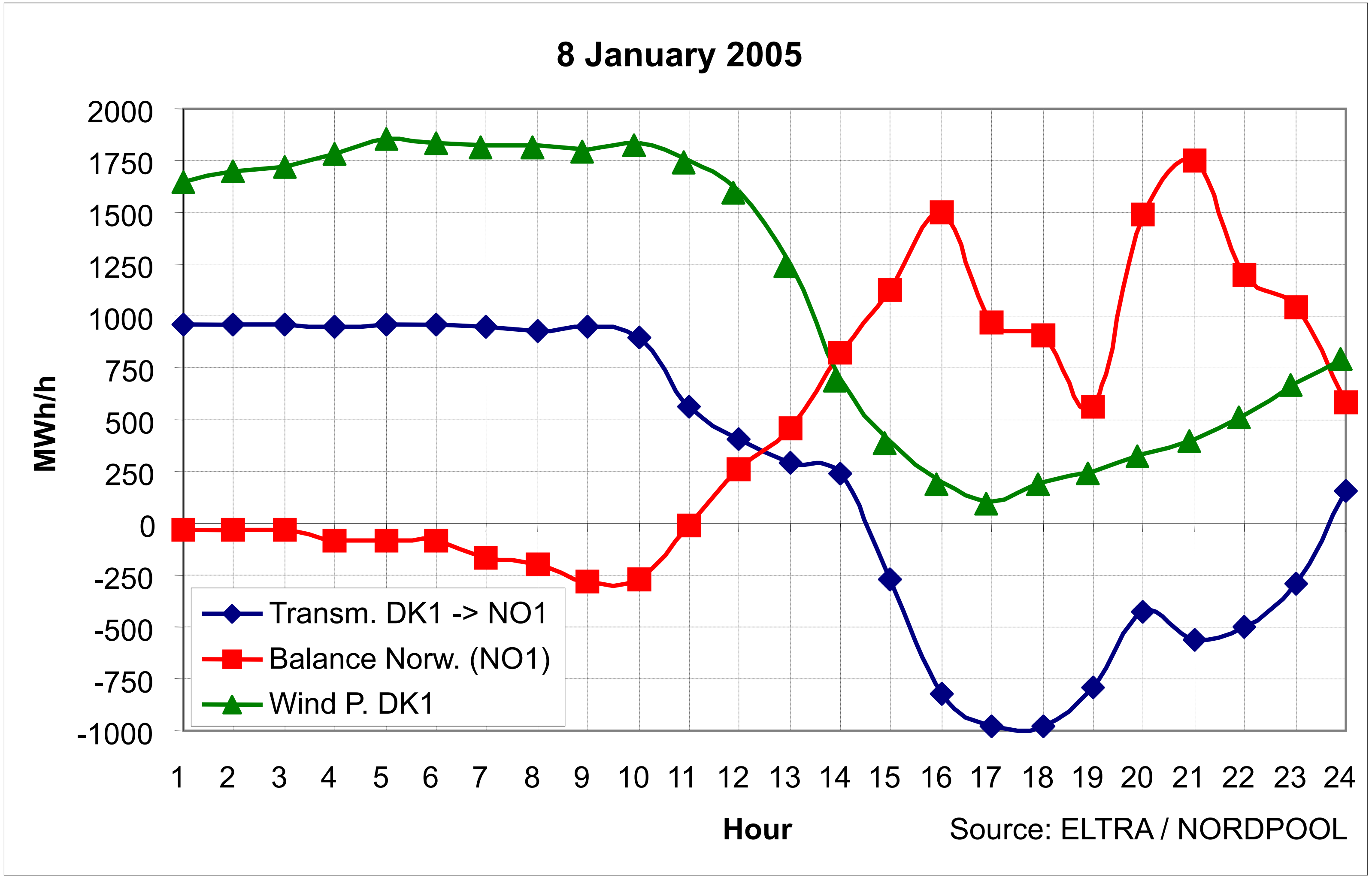
- **Wind power results in the same type of variations/ uncertainties (and solutions) as hydro power.**
- **But: Time perspective is much shorter!**



Example from Denmark, when a storm front hit the country: -1800 MW in 6 hours



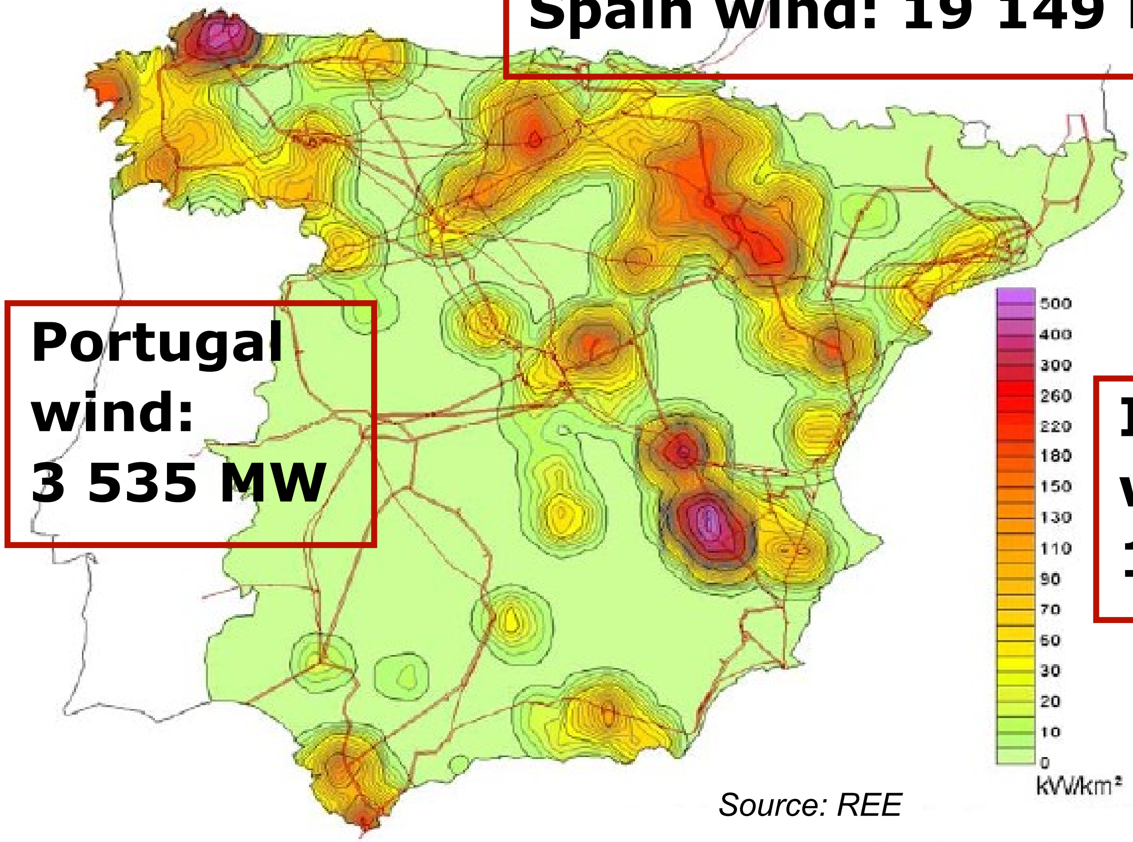
180 km



Wind Power and Transmission capacities

Spain wind: 19 149 MW

Portugal wind: 3 535 MW



Source: REE

Ireland wind: 1260 MW

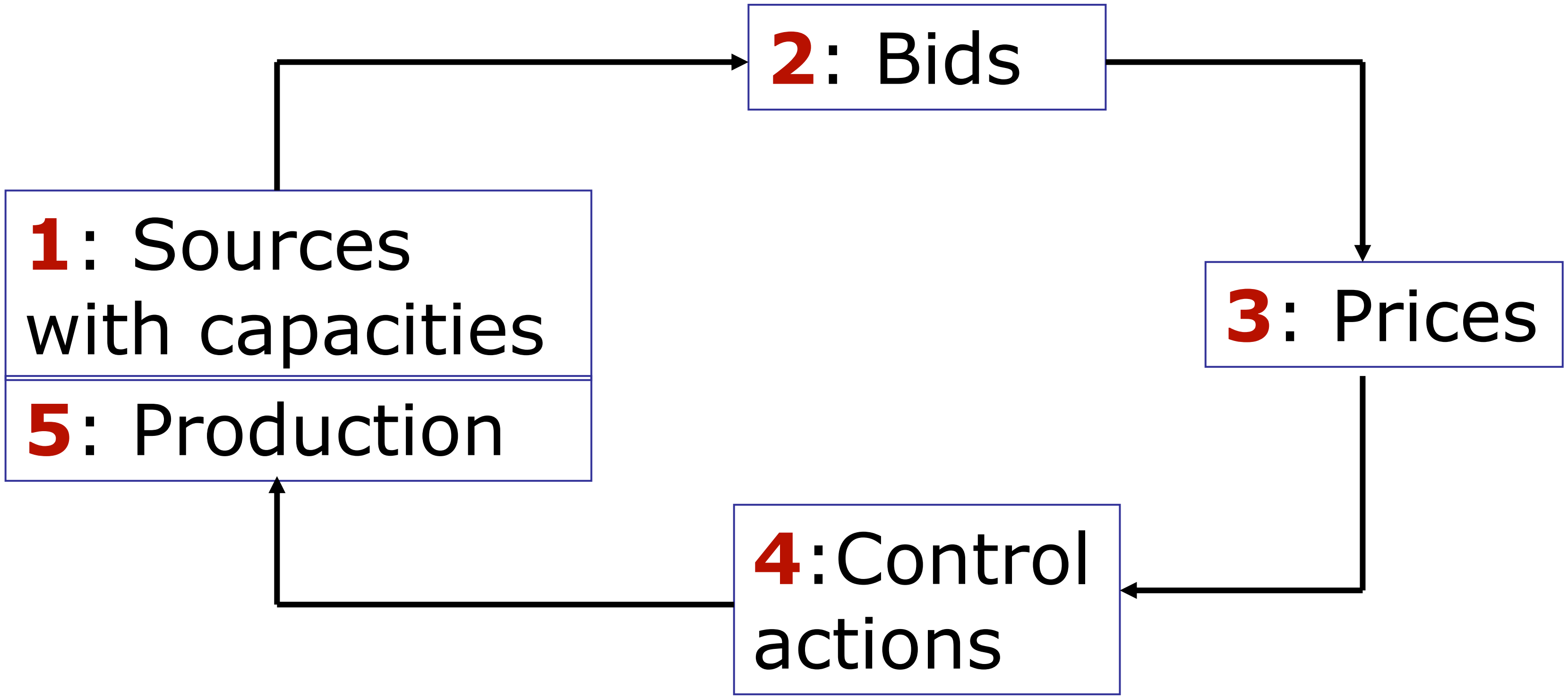
	Wind Energy 2008
Sp	11 %
Po	15 % -09
Ir	9 %

	Wind max share
Sp	53 %
Po	71 %
Ir	48 %

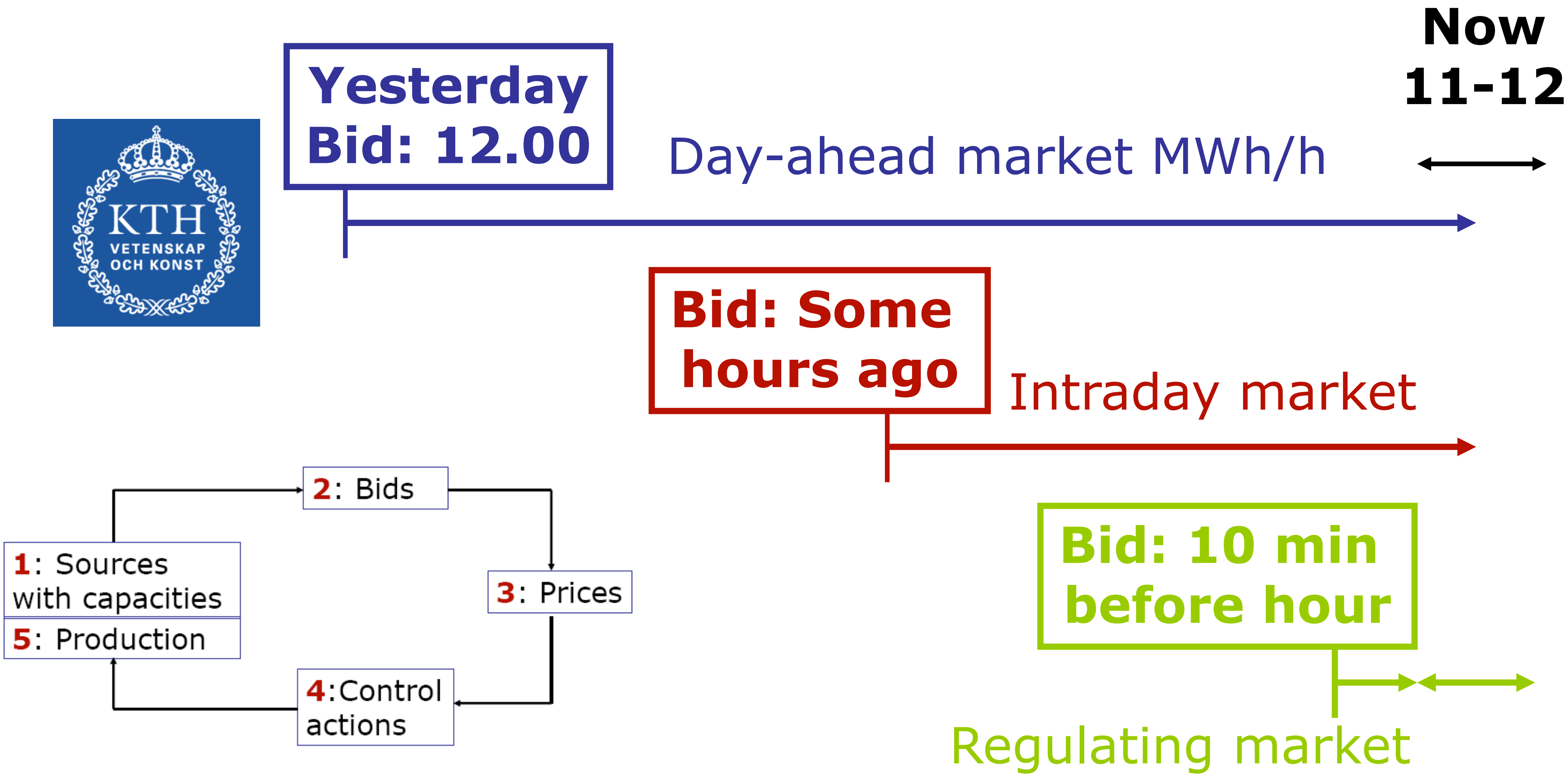
- Portugal –Spain: 1200 MW
- Spain – France: 1200 MW
- Spain – Morocco: 650 MW

- Ireland - Scottland: 450 MW
- Planned: +850 MW

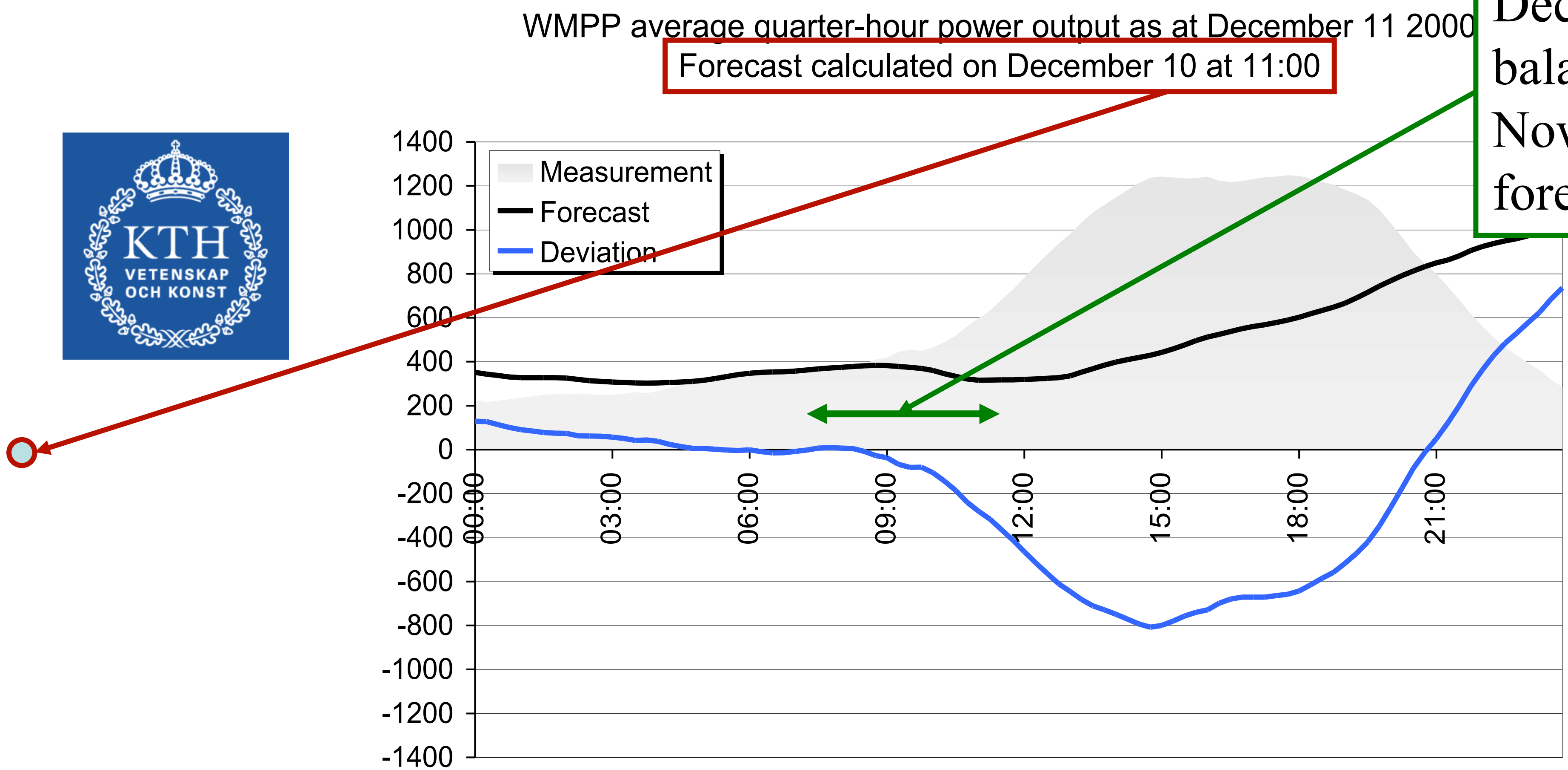
Pricing in power markets - 1



Pricing in power systems - 2



On up-dated forecasts



Decision for balancing: Now improved forecast!

Pricing in power systems - 3

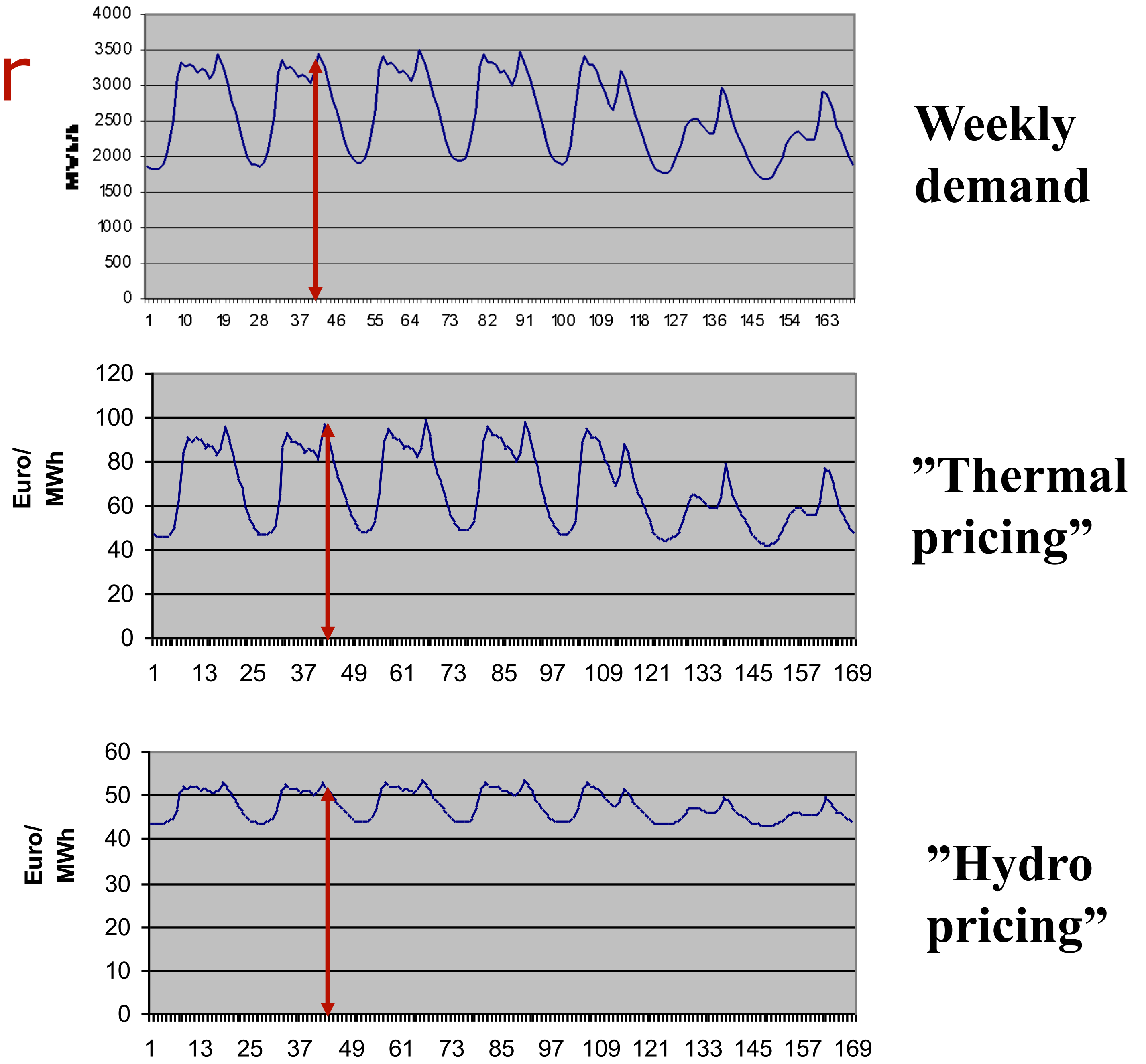
Challenges:

- **Bid planning** considering opportunities and uncertainties
- **Production planning** and operation considering opportunities and uncertainties
- **Estimation of** future **prices** in different systems
- **Stochastic optimization** approach needed
- **Intra hour modelling**

Pricing in power systems - 4

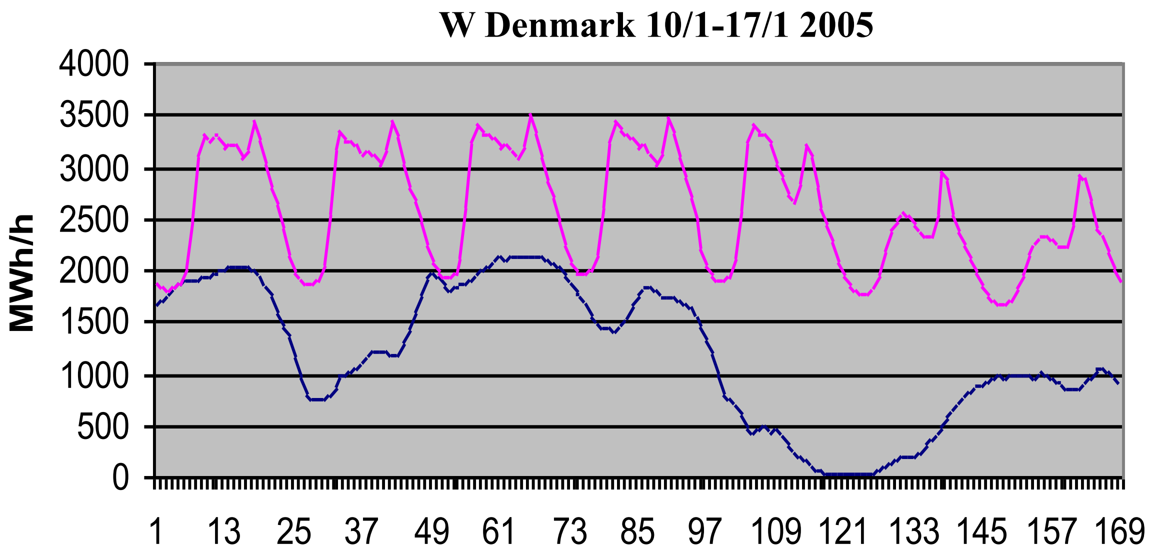
With an assumption of perfect competition:

- Prices are based on production marginal costs
- Low costs units are used first
- Higher load ➔ higher prices:

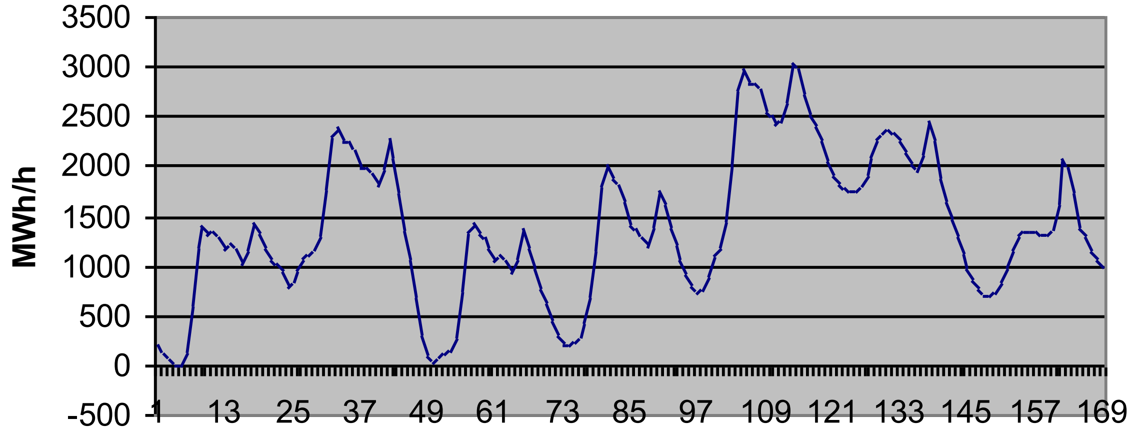


Pricing in presence of variable sources (e.g. wind)

- Wind power has a marginal cost ≈ zero
- The production level is depending on wind speed
- It is not easy to make good long term (hours) forecasts
- Other units have to cover the net load = demand - wind



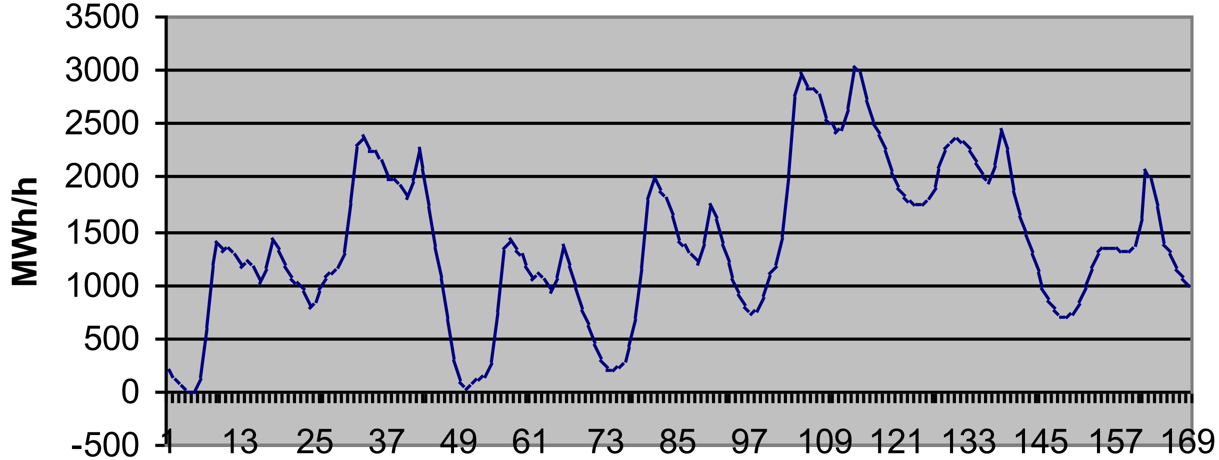
Weekly demand + wind



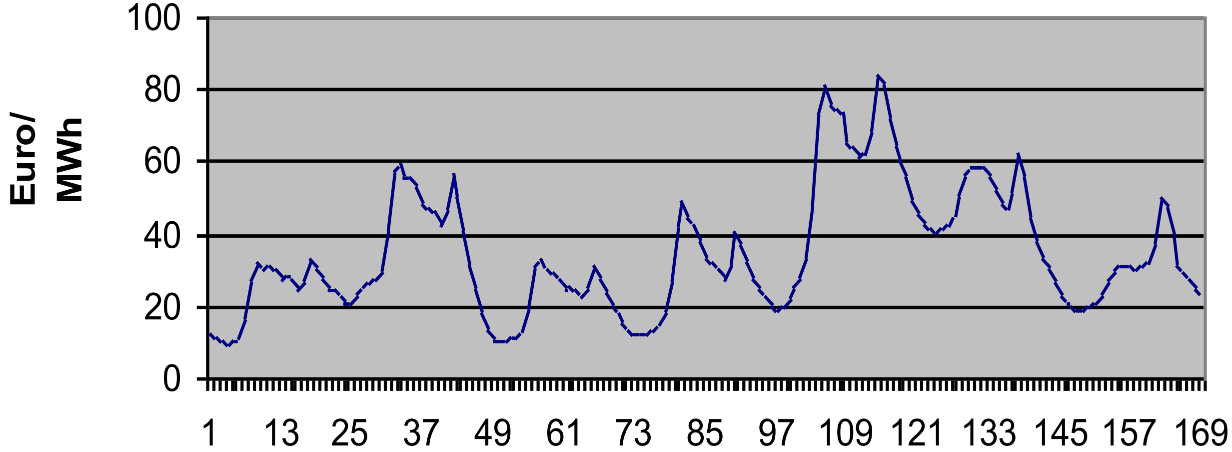
Weekly net demand

Pricing in presence of variable sources

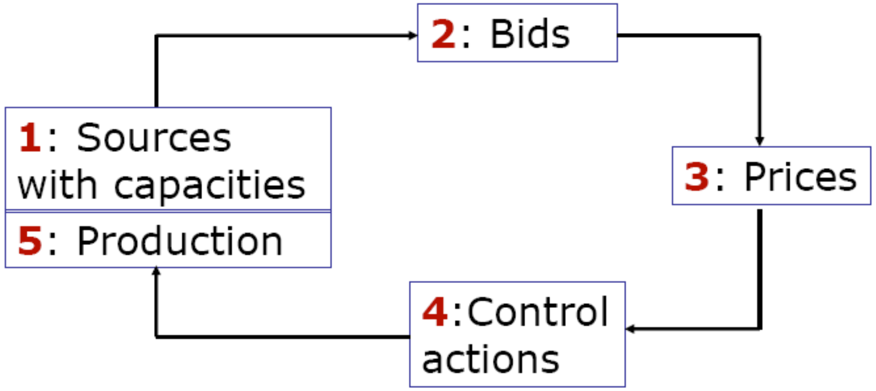
- Other units have to cover the net load = demand – wind
- The other units production is controlled by price!
- ➔ more volatile price
- **Note: This is independent of "fixed price" etc**

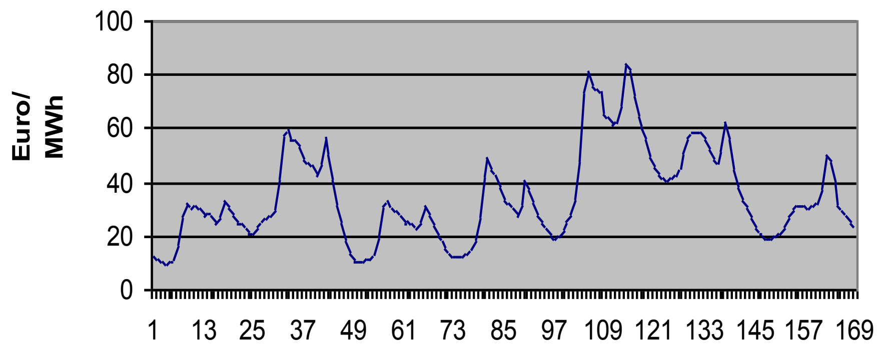


Weekly net demand



"Thermal pricing"





Some comments:

- Wind power forecasts are more uncertain ➔ larger volumes on shorter markets
- Wind power does NOT have a typical daily pattern ➔ No ”typical” pattern of prices either.
- ➔ One can not, e.g., count on ”load your electric car during the night”.

Impact on operation, inter-area trading and investments

Operation:

- Larger variation and larger uncertainties ➔ prices on day-ahead markets do not reflect marginal costs

Interarea trading:

- Large amounts of wind power in one area ➔ large interest to buy this in neighboring systems since marginal cost is low. ➔ **Larger need for trading**

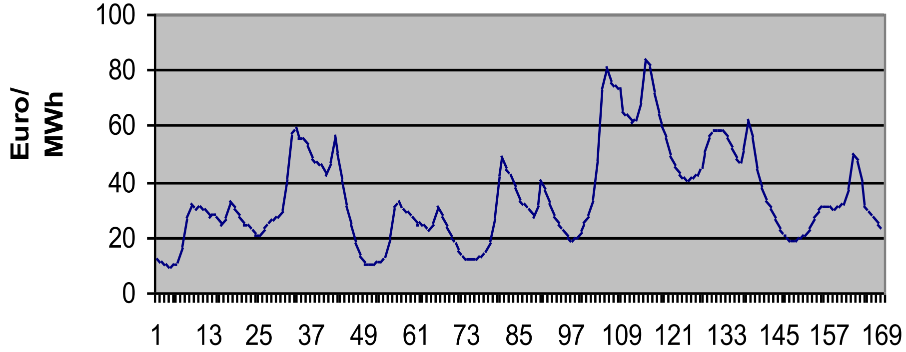
Investments:

- Also so-called ”base-plants” will have an economic value to be more flexible, since the power price can be below their marginal operation cost.

Solutions and competition

Assume a system with large price variation:

- ➔ Three types of "business opportunities"



More trading with neighbors

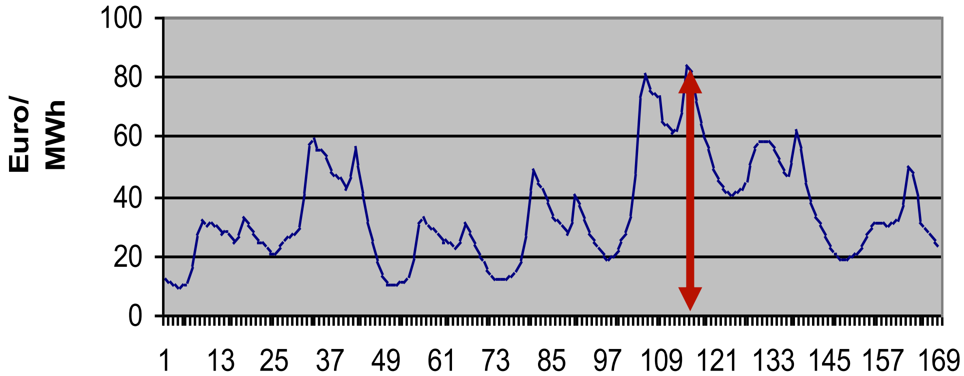
Demand side management

Flexible plants

- There is a competition between these methods.
- Much transmission reduces price changes ➔ less interest in DSM

Production capacity challenge

- Who wants to invest in rarely used units? With wind power the utilization time decreases
- If not we get ”capacity deficit”

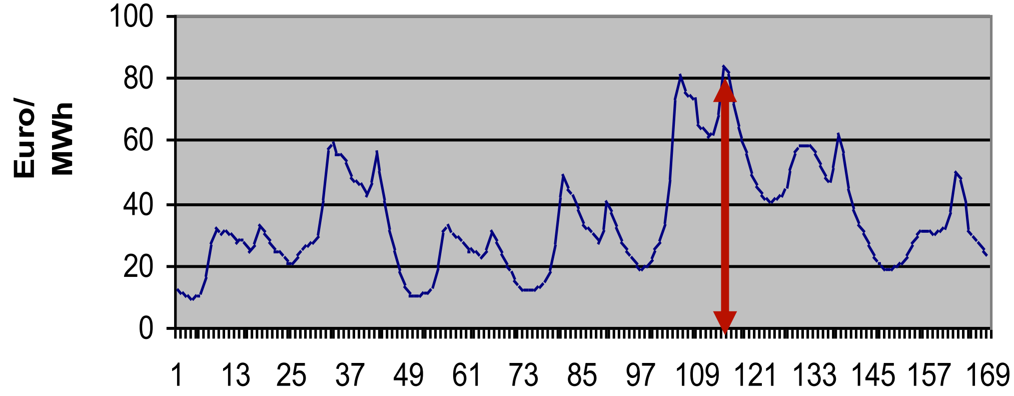


Deregulation

- **Before deregulation:** most system operators kept ”enough” reserves and ”extra” reserves with trading possibilities with other systems
- **”Good” deregulation:** open competition also cross border ➔ no double margins any longer ➔ increased LOLP

Capacity challenge

- Three important system parameters / variables



Maximum price

- Extreme prices for few hours can finance peak plants

System reliability

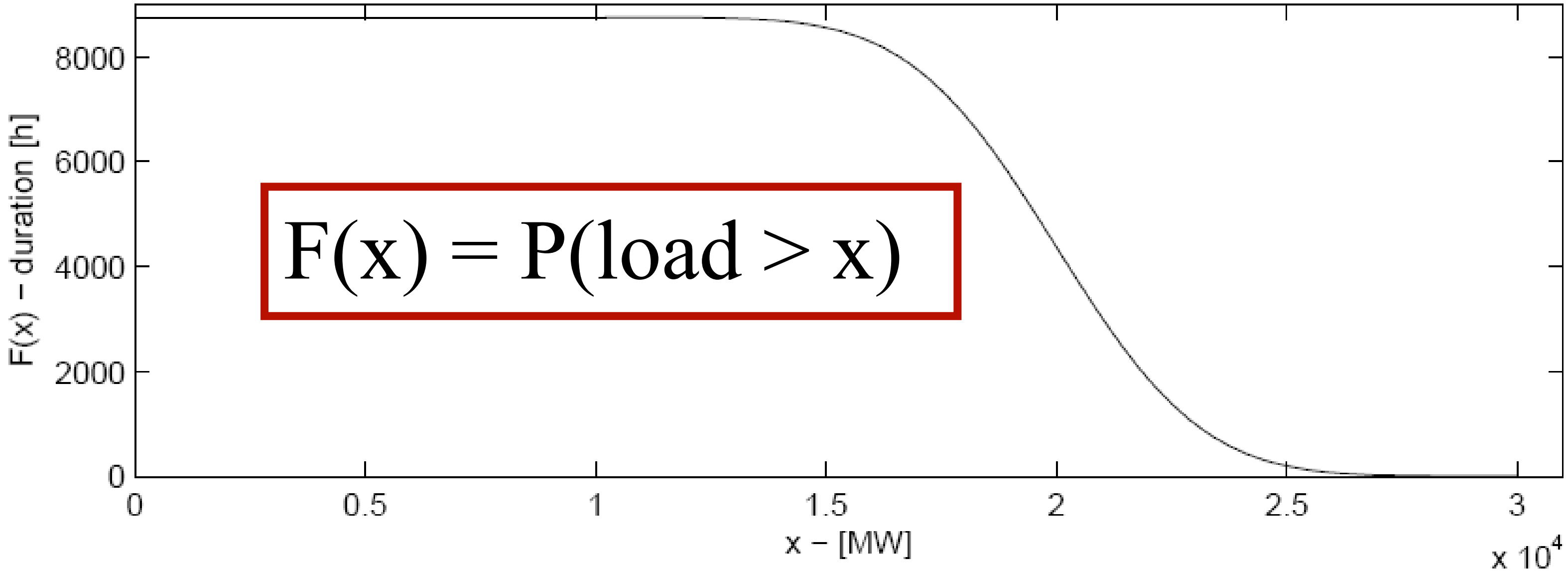
- Requirement of max LOLP

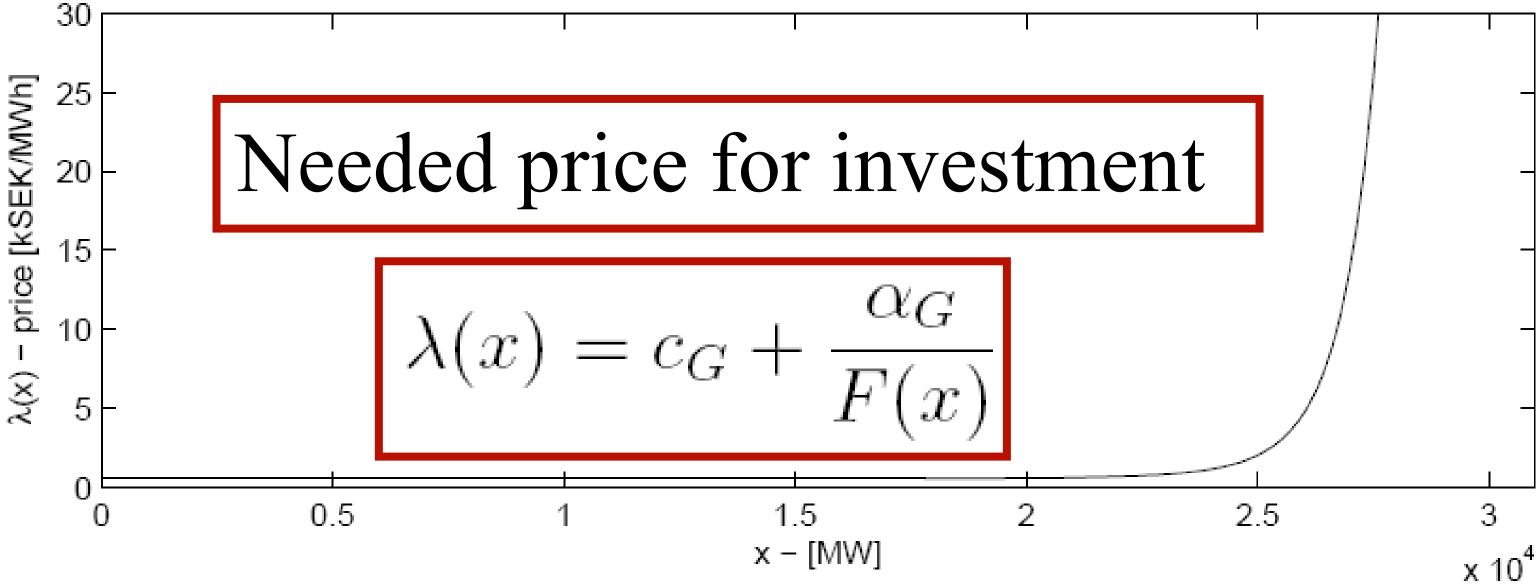
Subsidized plants

- MW of power plants not paid with market price

- One of these three can be calculated from the other two.
- **Comment**: Wind power capacity credit reduces the utilization time of the peak unit.

Concerning market interest to invest in "last" unit





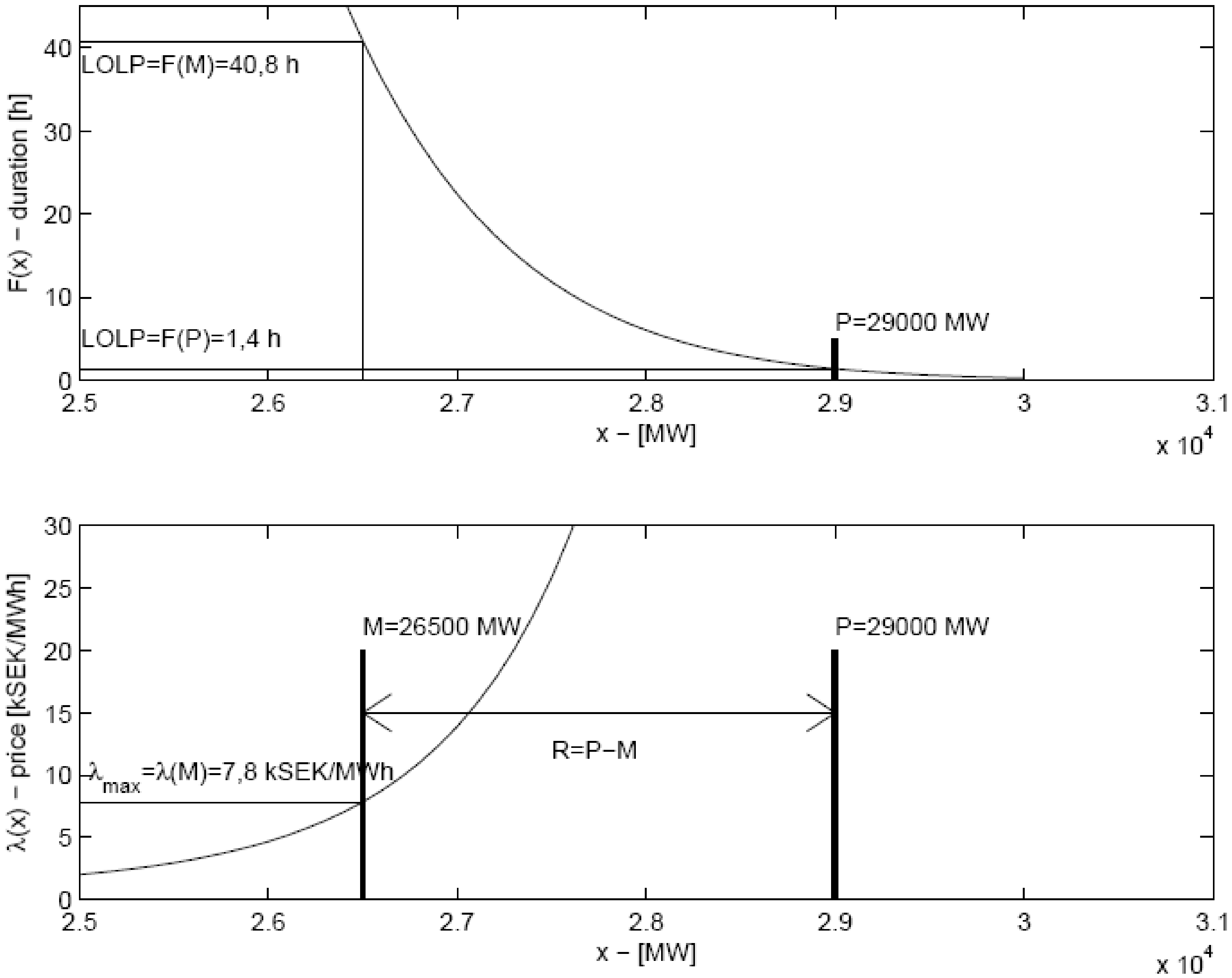
The cost of a gas turbine is assumed to *aG* = 300 kSEK/MW, year and *cG* = 0.5 kSEK/MWh

Concerning market interest to invest in "last" unit

x - load level MW	$F(x)$ - duration h/year	$\lambda(x)$ - needed price kSEK/MWh
>25500	121.8	> 3.0
>26000	71.8	>4.7
>26500	40.8	>7.8
>27000	22.4	>13.9
>27500	11.8	>25.9
>28000	6.0	>50.3
>28500	3.0	>102.1
>29000	1.4	>215.7
>29500	0.6	>473.9
>30000	0.3	>1081.8

- Lennart Söder "Analysis of Pricing and Volumes in Selective Capacity Markets" IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 25, NO. 3, AUGUST 2010

Concerning market interest to invest in “last” unit - 9

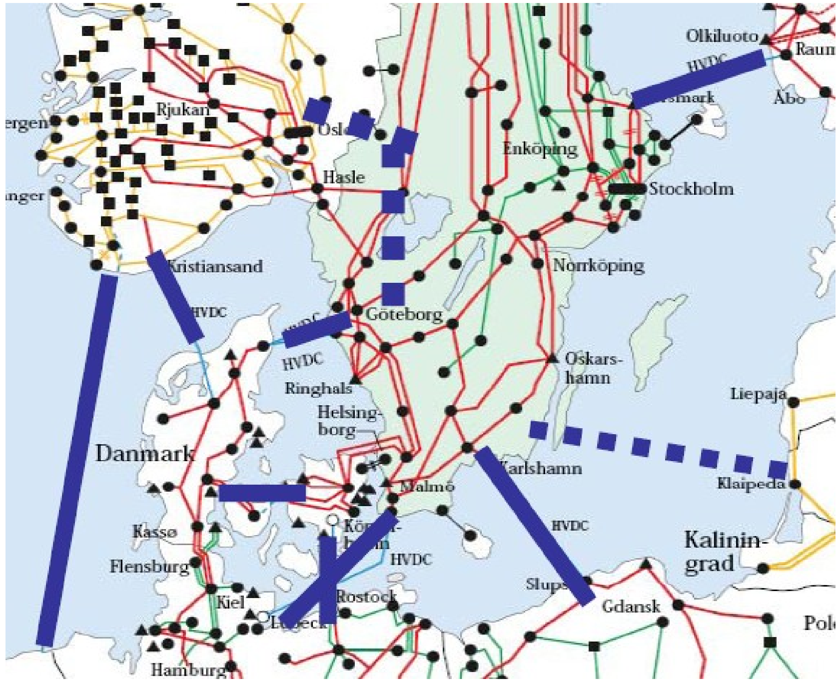


Peak load resources in current Swedish market

- TSO purchases PLR maximum 2000 MW
- The power is bid into Nordpool spot
- The bid price = latest accepted bid at Nordpool
- Not used bids are moved to the regulating market.
- There is a maximum imbalance price of 5000 Euro/MWh

Transmision capacity challenge

- From power system security point of view, there should be ”enough” margins.



Deregulation

- Higher economic pressure ➔ requirements to operate closer to limits
- **But:** Controllability increases possibility to transfer more with the same stability margin.

Risk management of TRM
Transmission Reserve Margin

Challenge

Method

Uncertain load development

The Ornstein-Uhlenbeck process

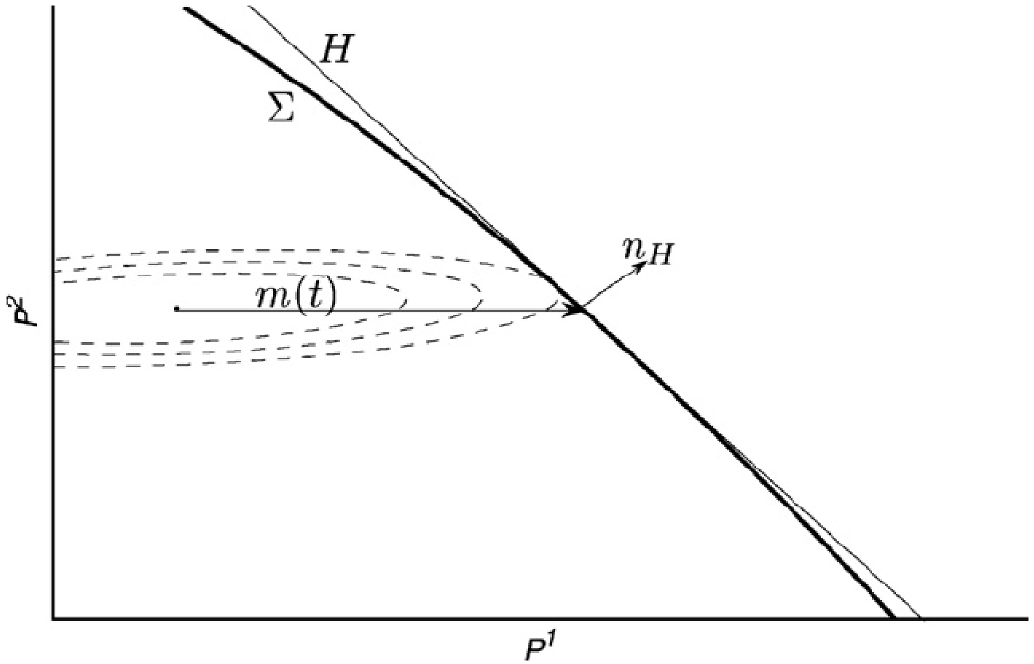
Calculate risk for voltage collapse within time δ

hyperplane approximation

Select optimal counter trade = tertiary control = regulating power bids

Impulse control (stochastic control)

Risk management of TRM Transmission Reserve Margin



- Perninge, Söder "On the Validity of Local Approximations of the Power System Loadability Surface", IEEE Transactions on Power Systems, February 2011
- Perninge, Söder "Risk Estimation of the Distance to Voltage Instability using a Second Order Approximation of the Saddle-Node Bifurcation Surface, Electric Power System Research, February 2011

Transmission limits
Coordinated stabilizing control

Challenge

Many controllable components

Aim of control:

- Stabilize
- Accept higher transfer

1. Select signals
2. Identify system
3. Select method
4. Optimal parameters

Method

Many HVDC links

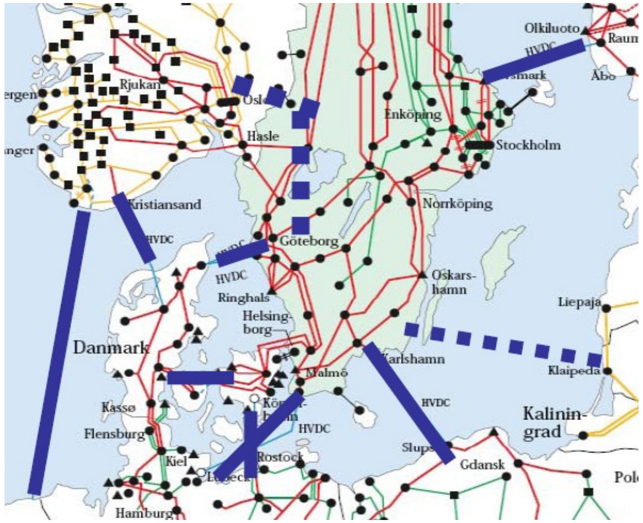
Aim of control:

- Small signal stability - Accept higher transfer

1. Use PMU
2. Disturb → Subspace Identification
3. E.g. LQG-control
4. Optimal parameters

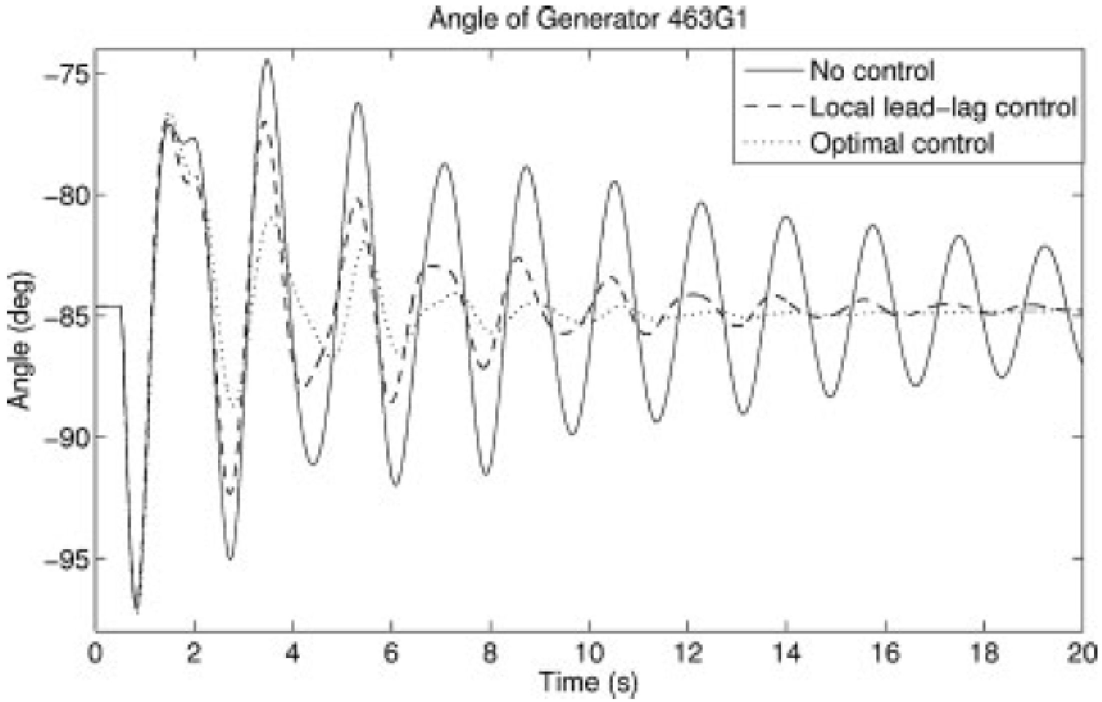
Linear
Quadratic
Gaussian

Transmission limits
Coordinated stabilizing control



HVDC – in operation

HVDC - planned



- Eriksson, Söder “Optimal Coordinated Control of Multiple HVDC Links for Power Oscillation Damping based on Model Identification”, European Transactions on Electrical Power, March 2011
- Eriksson, Söder “Wide-Area Measurement System Based Subspace Identification for Obtaining Linear Models to Centrally Coordinate Controllable Devices”, IEEE transactions on power delivery, March 2011

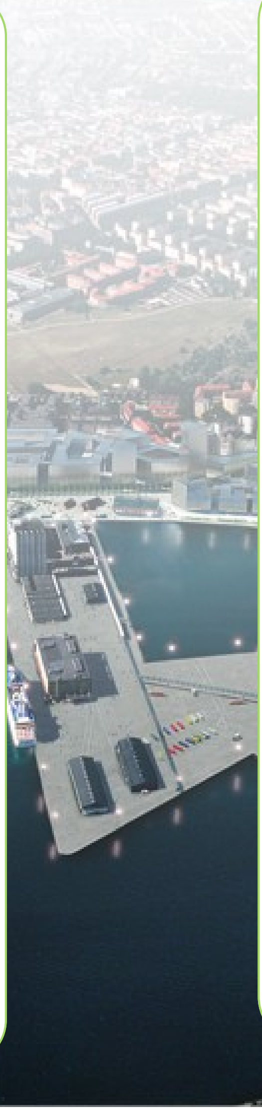
Summary

- More varible power ➔ higher price volatility
- The higher price volatility is needed since other power plants have to vary their production more
- This is independent of ”fixed price”, ”certificates” etc
- There is a true competition between transmission, DSM and flexible production.
- The capacity challenge increases with deregulation and with wind power capacity credit.

Stockholm Royal Seaport – *a future environmental city district and an international showcase*

Key Facts

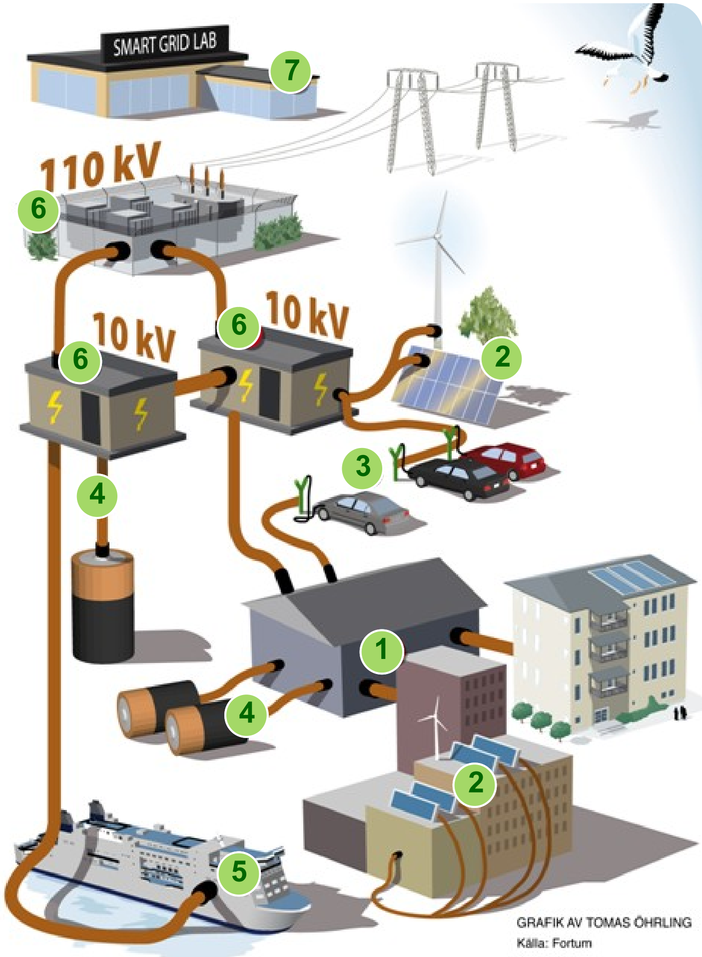
- **Area: 236 hectares. Land owned by the City of Stockholm.**
- **Building start: 2010**
- **Completion: 2025**
- **Current construction: soil remediation, infrastructure**
- **First occupancy: 2012**
- **New apartments: 10,000**



Key Facts

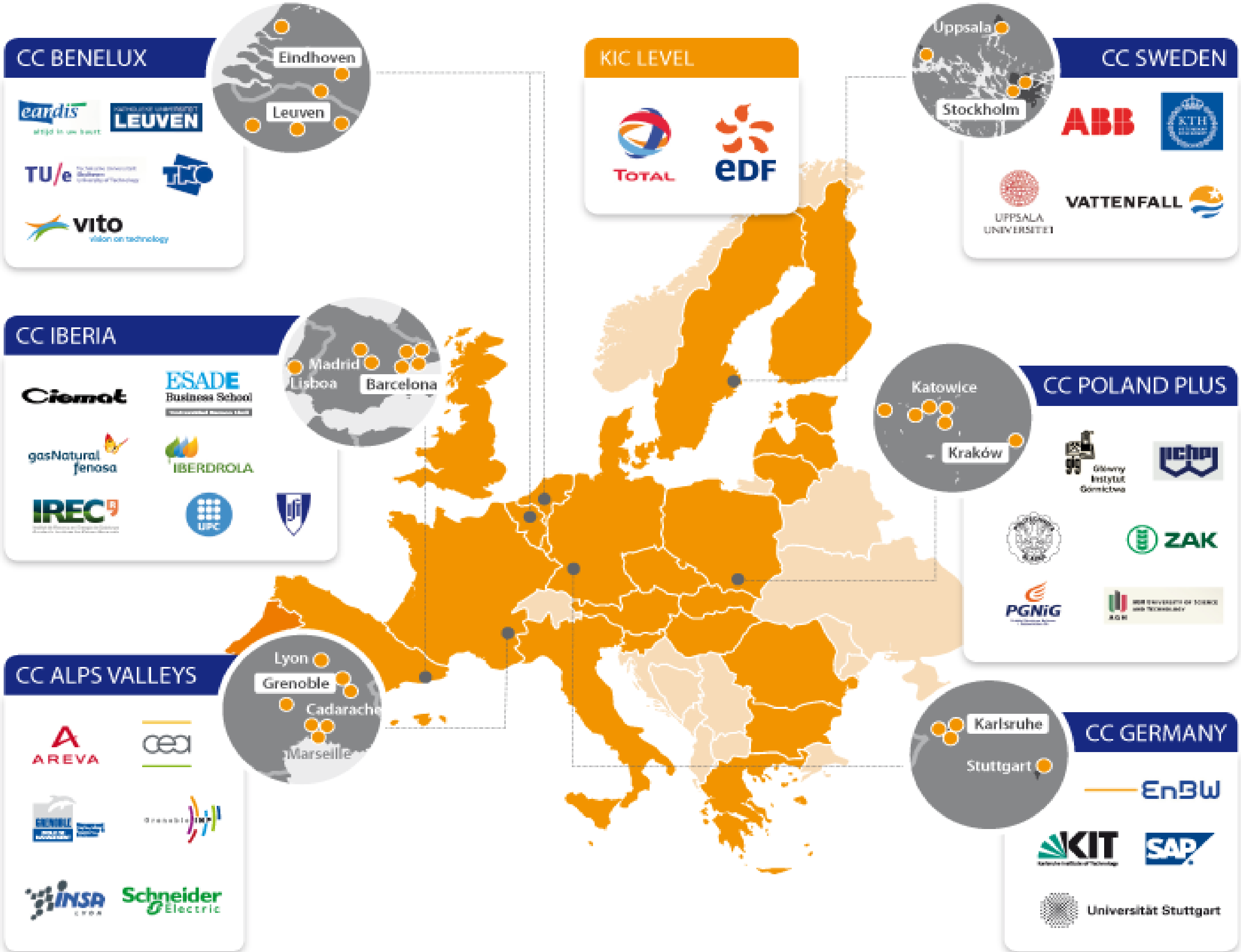
- **New work spaces: 30,000**
- **Commercial areas: 600,000 sqm**
- **Energy target: 55 kWh sqm/year**
- **Distance to city centre: 2,1 miles**
- **Infrastructure: Biogas buses, city tram, metro, district heating, new lanes for pedestrians and cyclists etc.**

Large-scale R&D investments into sustainable electricity systems in an urban environment



1. **Active homes and demand control**
   - Increased energy efficiency and peak levelling
2. **Dispersed local energy production**
   - Integration of local energy production
3. **Use of electric vehicles and smart charging**
   - An integrated infrastructure for charging electric vehicles
4. **Energy storage supporting customers and grid**
   - Improved grid quality and levelling out of power peaks
5. **Smart and electrified port**
   - Reduction of CO_2 emissions with high voltage connections for the ships
6. **Smart grid stations**
   - Improved operational safety through increased automation
7. **Centre for operations, research and follow-up**
   - Operation, research and development as well as follow up of the smart grid

KIC InnoEnergy – A world class alliance of top European players with a proven track record



- 13 companies, 10 research institutes, 13 universities
- ~50% industry partners (incl. associated partners)
- >50% of key research players in Europe
- Covering the whole energy mix
- Knowledge triangle balanced along all dimensions
- Strong connection with VCs and local governments

35

KIC InnoEnergy will bring innovation to the whole energy-mix coherent with the SET Plan

CC BENELUX

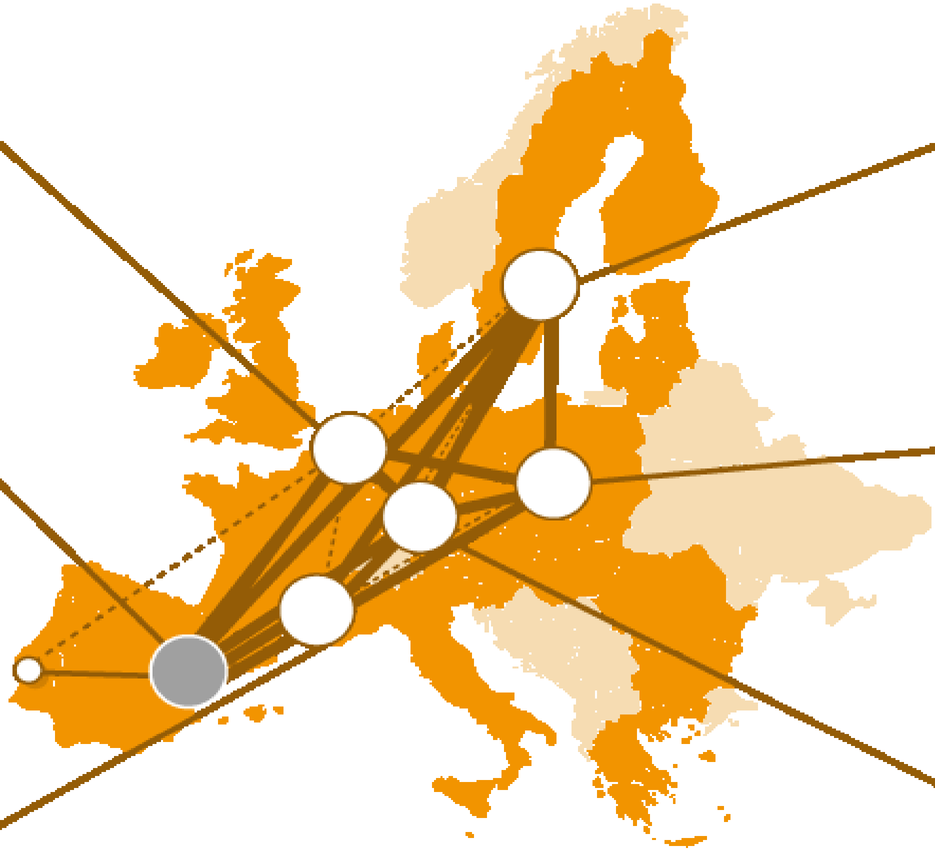
- **Intelligent Energy-efficient Buildings and Cities**
- *Setting up an intelligent house with minimum energy needs*

CC IBERIA

- **Renewables (Wind, CSP, Photovoltaics, Wave and Tidal energy)**
- *Demonstration project solar CSP*

CC ALPS VALLEY

- **Sustainable Nuclear & Renew-able Energy Convergence**
- *Nano-materials for high energy / high power batteries*



CC SWEDEN

- **European Smart Electric Grid and Electric Storage**
- *System and markets for the smart super grid of the future*

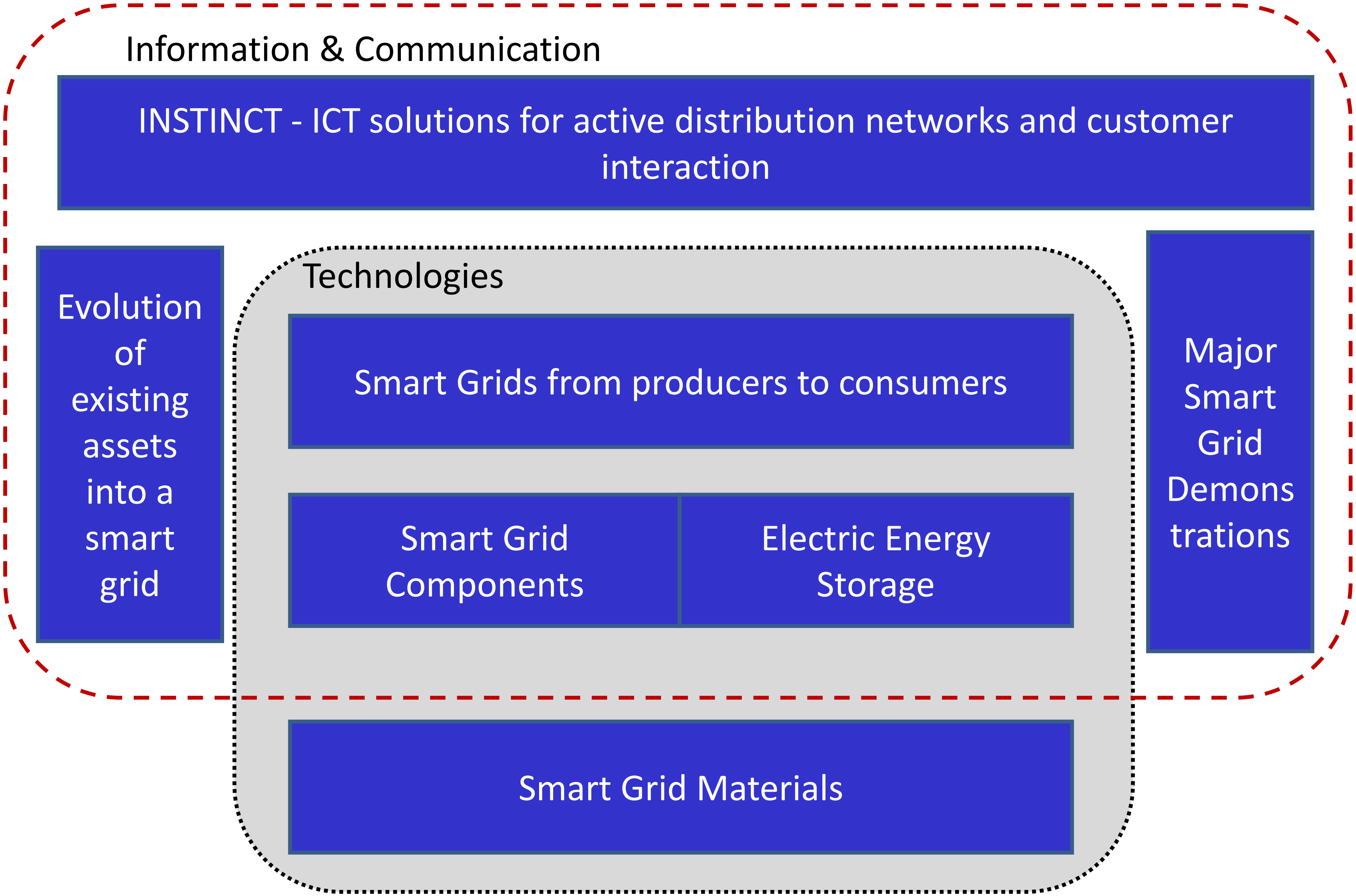
CC POLAND PLUS

- **Clean Coal Technologies**
- *Gasification of coal with CO2 internal reduction*

CC GERMANY

- **Energy from Chemical Fuels**
- *Demonstration unit hybrid power plant based on micro gas turbine*

KIC InnoEnergy CC Sweden



Smart grids from power producers to consumers

***WP1**: Management and Communication*

***WP2**: Operation and design of Smart Grids with new technologies*

***WP3**: Application of Smart Grids*

***WP4**: Result Dissemination and exploitation plan.*

***WP5**: Market Analysis*

Smart Grids

From Producers to Consumers