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Pricing and congestion management in coupled European wholesale markets

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Background and outline

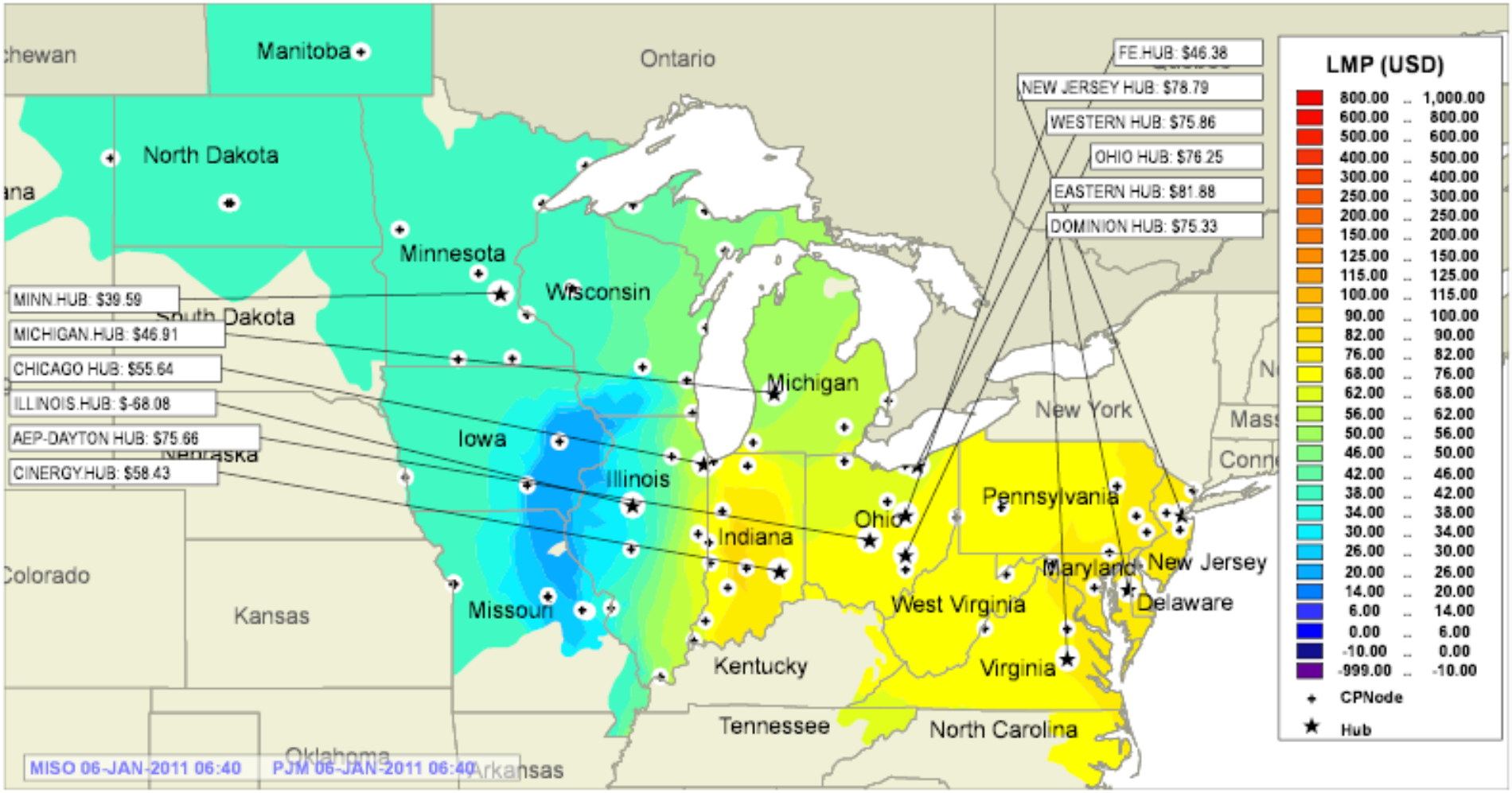
- European day-ahead market integration
  - Target model
    - Energy only regional markets
    - Market coupling between regional markets
- Congestion Management
  - Locational pricing variants
    - Nodal pricing – Benchmark
    - Zonal pricing – Available Transfer Capacity (ATC) model
    - Zonal pricing – Flow-based Market Coupling (FBMC) model
- Future developments
  - Integration of intraday and balancing markets

Why is the grid so important?

- The grid integrates geographically dispersed markets
- The grid affects the formation of prices
  - The technology for transmitting electricity presents some special challenges to the competitive markets model
    - Electricity is very costly to store
    - Supply must equal demand at every instant in time
    - Severe capacity constraints
    - Power flow equations and loop flow
- Short run relevant costs for transmission
  - Losses
  - Ancillary services, reactive power
  - Congestion cost
    - The opportunity cost that results from out-of-merit order dispatch, i.e. the cost of not being able to dispatch the cheapest generators first

Congestion Management

- Objective
  - Optimal economic dispatch
    - Max social welfare (consumer benefit – production cost)
    - S.t. thermal and security constraints
  - Gives the value of power in every node, i.e. nodal prices
    - Benchmark
- Different methods to realize optimal dispatch
  - Nodal prices, Flowgate prices, Optimal re-dispatch…
- Provide price signals
  - For efficient use of the transmission system
  - For transmission, generation and load upgrades



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Midwest ISO Market data is based on Eastern Standard Time (EST) while PJM Market data is based on Eastern Prevailing Time.

PJM – 51 mill people/max load 145 000 MW/730 TWh/650 members/8700 nodes

Europe 2007

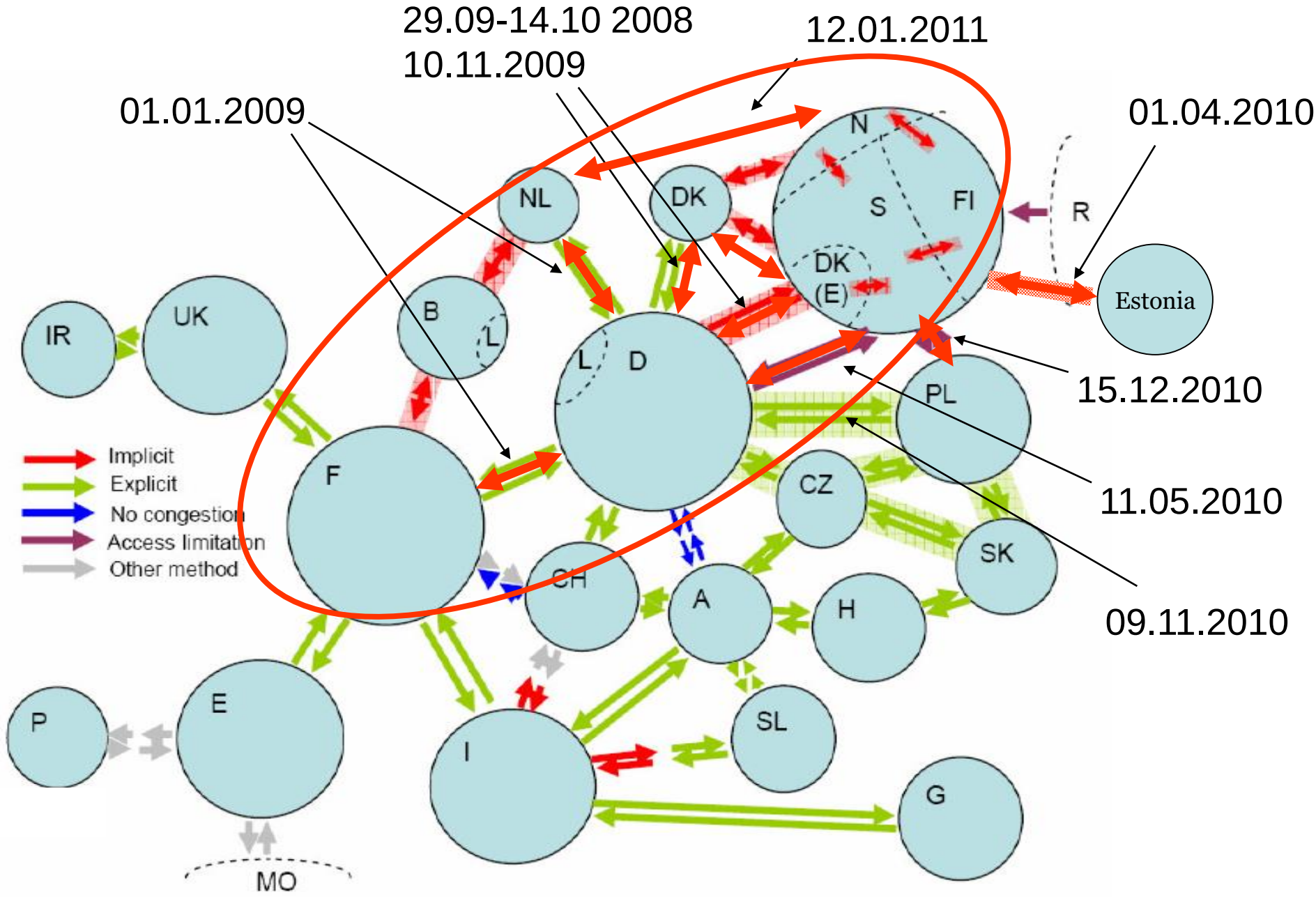
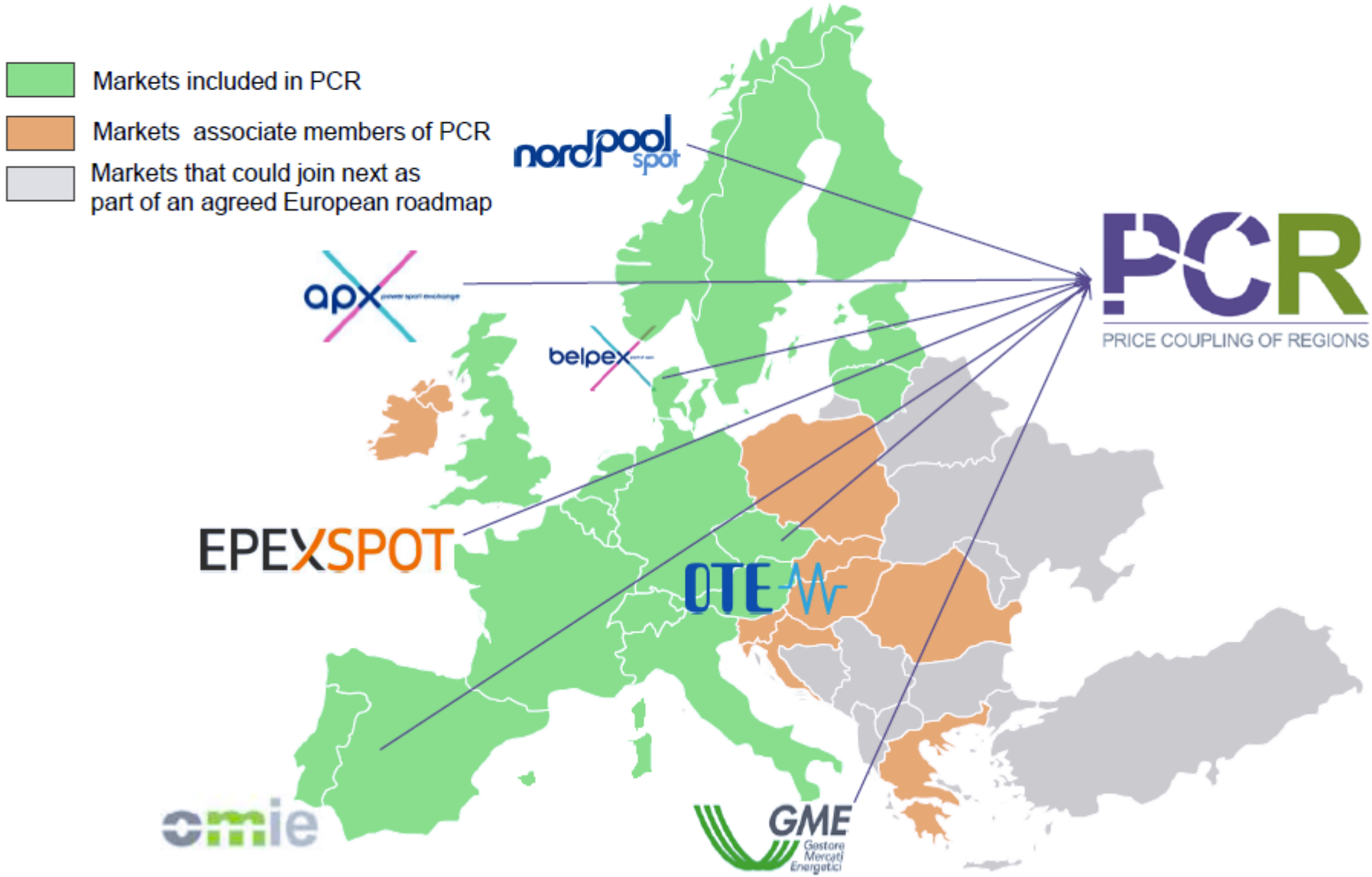


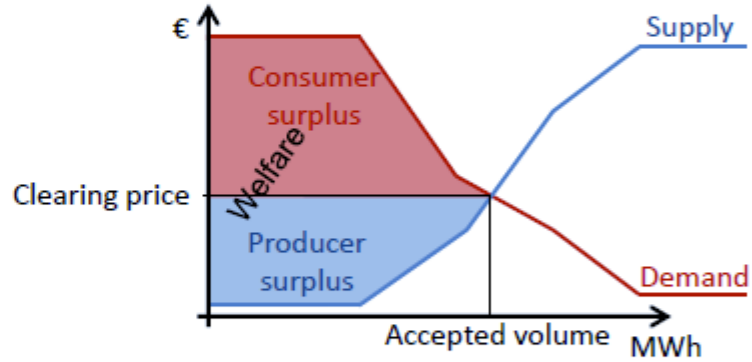
Figure 4.1 – Day-ahead transmission capacity allocations across Europe (updated June 2007)

Towards the Single European Market: Next Steps



ALGORITHM EUPHEMIA

- EUPHEMIA is an algorithm that solves the market coupling problem on the PCR perimeter
  - EUPHEMIA stands for: EU + Pan-European Hybrid Electricity Market Integration Algorithm
- It maximises the welfare of the solution
  - Most competitive price will arise
  - Overall welfare increases
  - Efficient capacity allocation

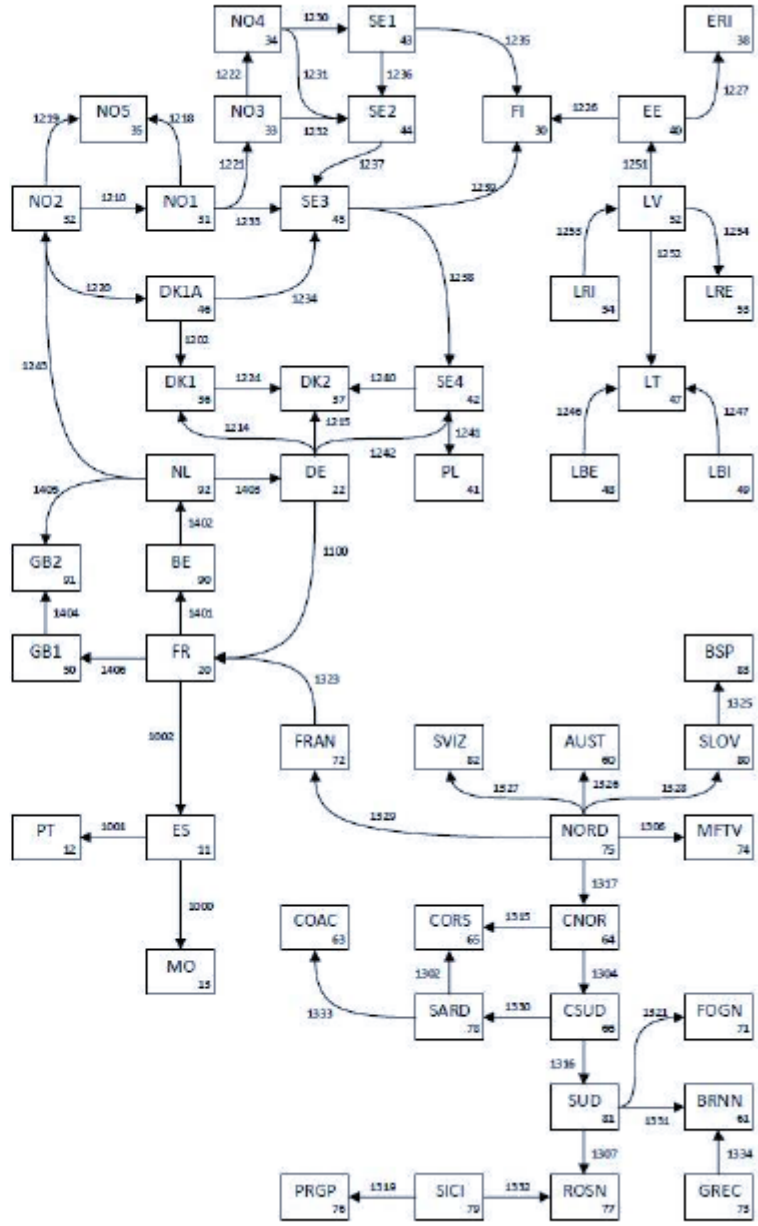


Algorithm has been tested using real 2011/2012/2013/2014 daily order books (around 50 bidding areas and 60 ATC lines)

PCR
PRICE COUPLING OF REGIONS

MARKET DATA

- Each PX (Market) operates several bidding areas
- All bidding areas are matched at the same time
- A different price can be obtained for each bidding area
- The price for the bidding area must respect maximum and minimum price market boundaries



NETWORK DATA AND BALANCE CONSTRAINTS

The energy balance concept is defined as: The global supply minus the losses must be equal to the global demand of all markets involved. Depending on the manner the interconnections are modeled, there are the following:

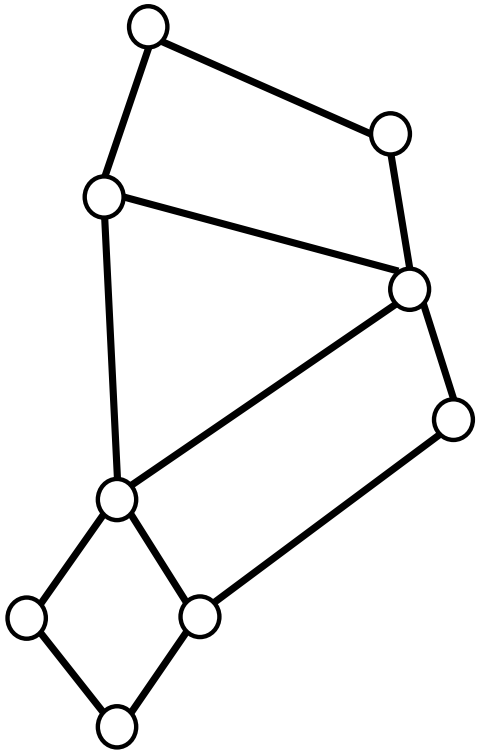
- ***ATC network model:*** The network is described as a set of lines interconnecting bidding areas. The nomination of the line can be made up to its Available Transfer Capacity (ATC)

- ***Flow-based network model:*** Also known as PTDF model, with all bidding areas connected in a meshed network. It expresses the constraints arising from Kirchhoff's laws and physical elements of the network in the different contingency scenarios considered by the TSOs. It translates into linear constraints on the net positions of the different bidding areas

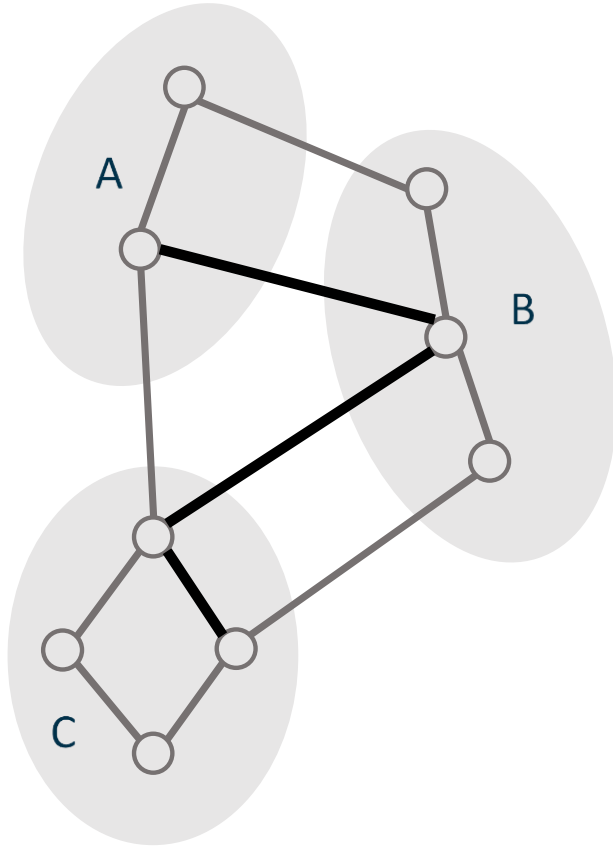
- ***Hybrid network model:*** Some bidding areas are connected using the Flow-based network model; the remaining using the ATC network model

PCR
PRICE COUPLING OF REGIONS

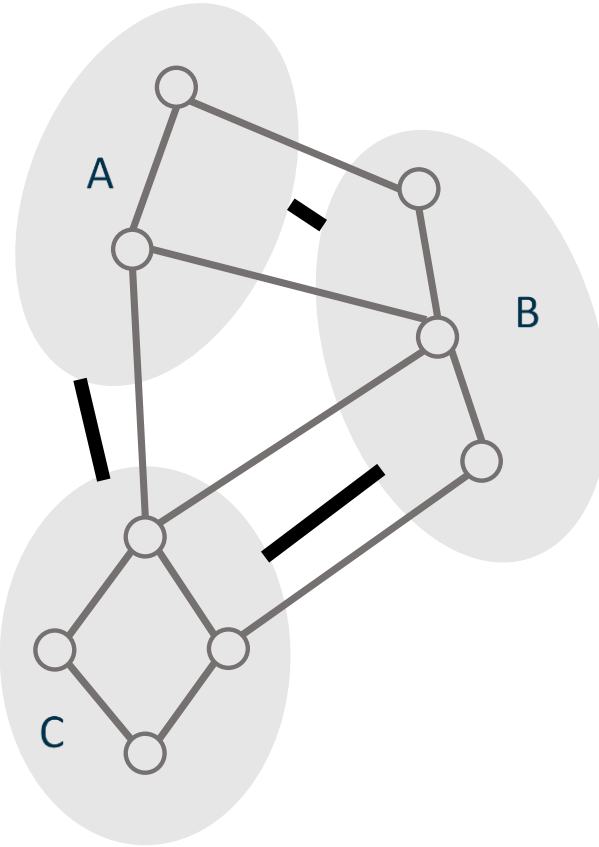
Locational pricing variants



Nodal FB model



Zonal FB model



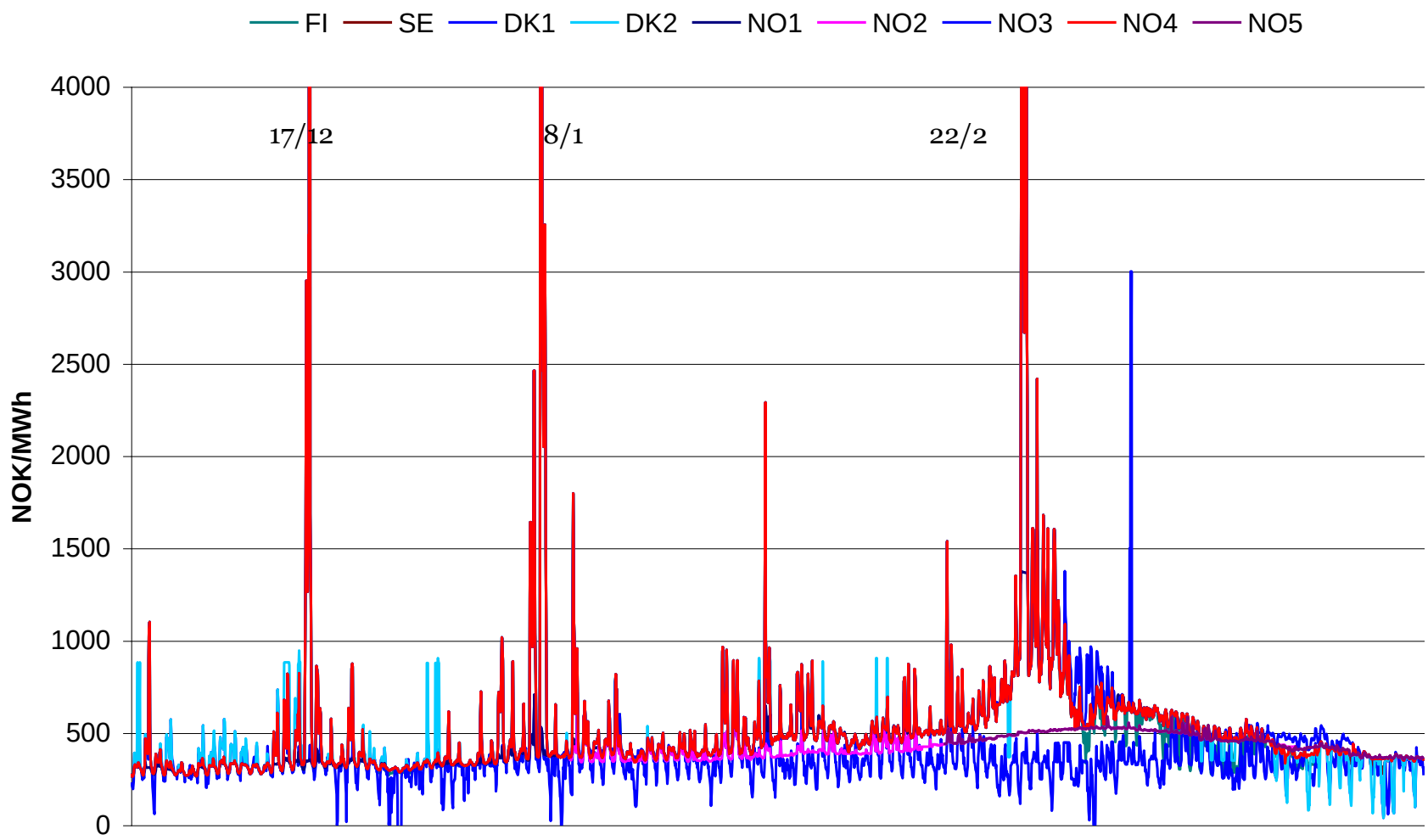
ATC model

Nodal pricing versus ATC zonal pricing

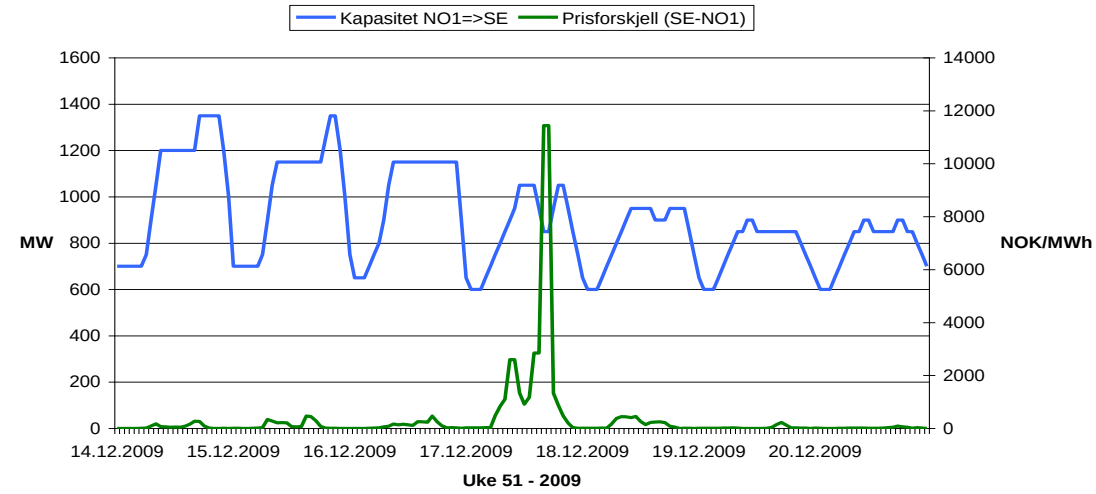
- If adding individual link capacities to set ATC
  - The model is a relaxation of the nodal price model
  - Will typically result in infeasible solutions and need for re-dispatch
- Restrictions are added, i.e. ATC capacities are lower
- Trade-off
  - Too loose restrictions lead to costly re-dispatch
  - Too tight restrictions lead to too constrained market clearing
  - Nord Pool last 15-20 years

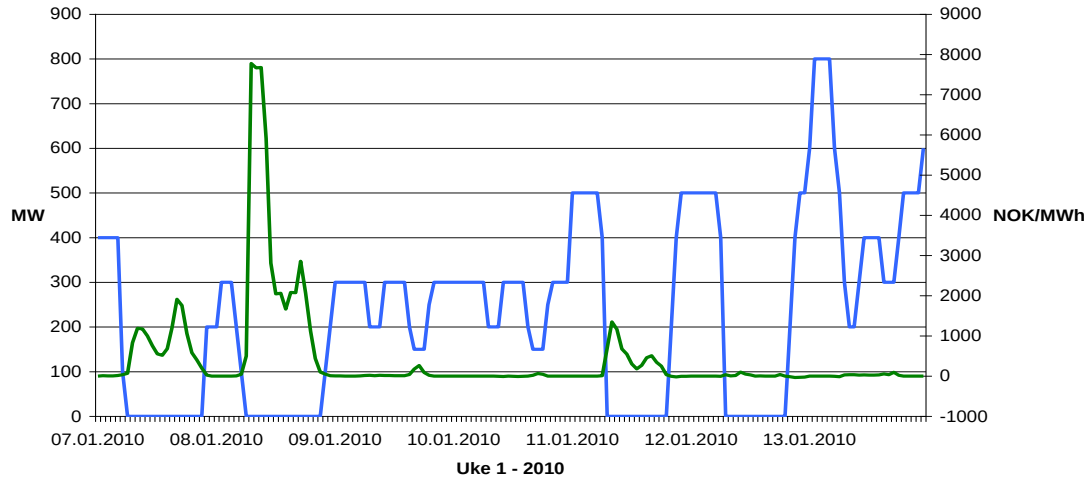
Aggregation – Nord Pool Spot

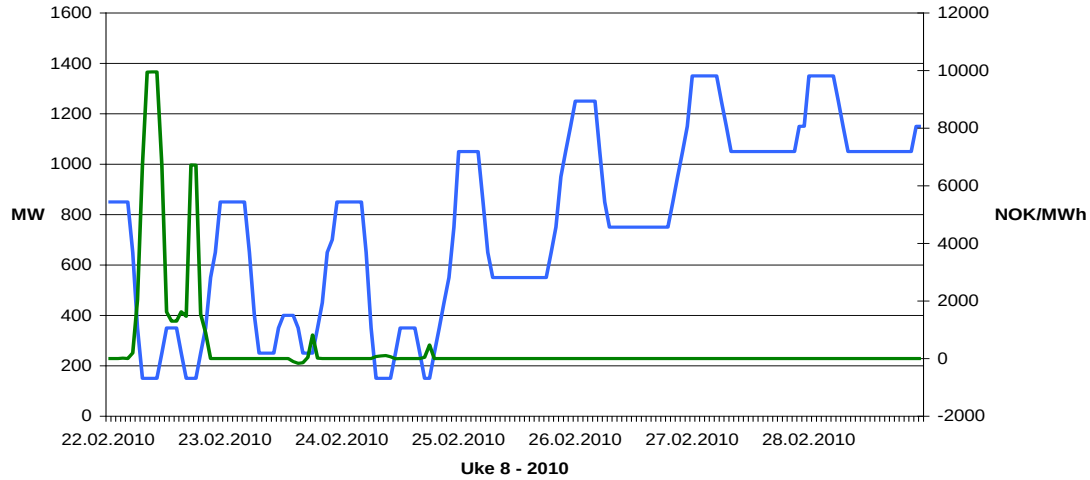
Elspot-prices
December 2009 – March 2010



Transfer capacities from Southern Norway to Sweden and price difference (NVE)





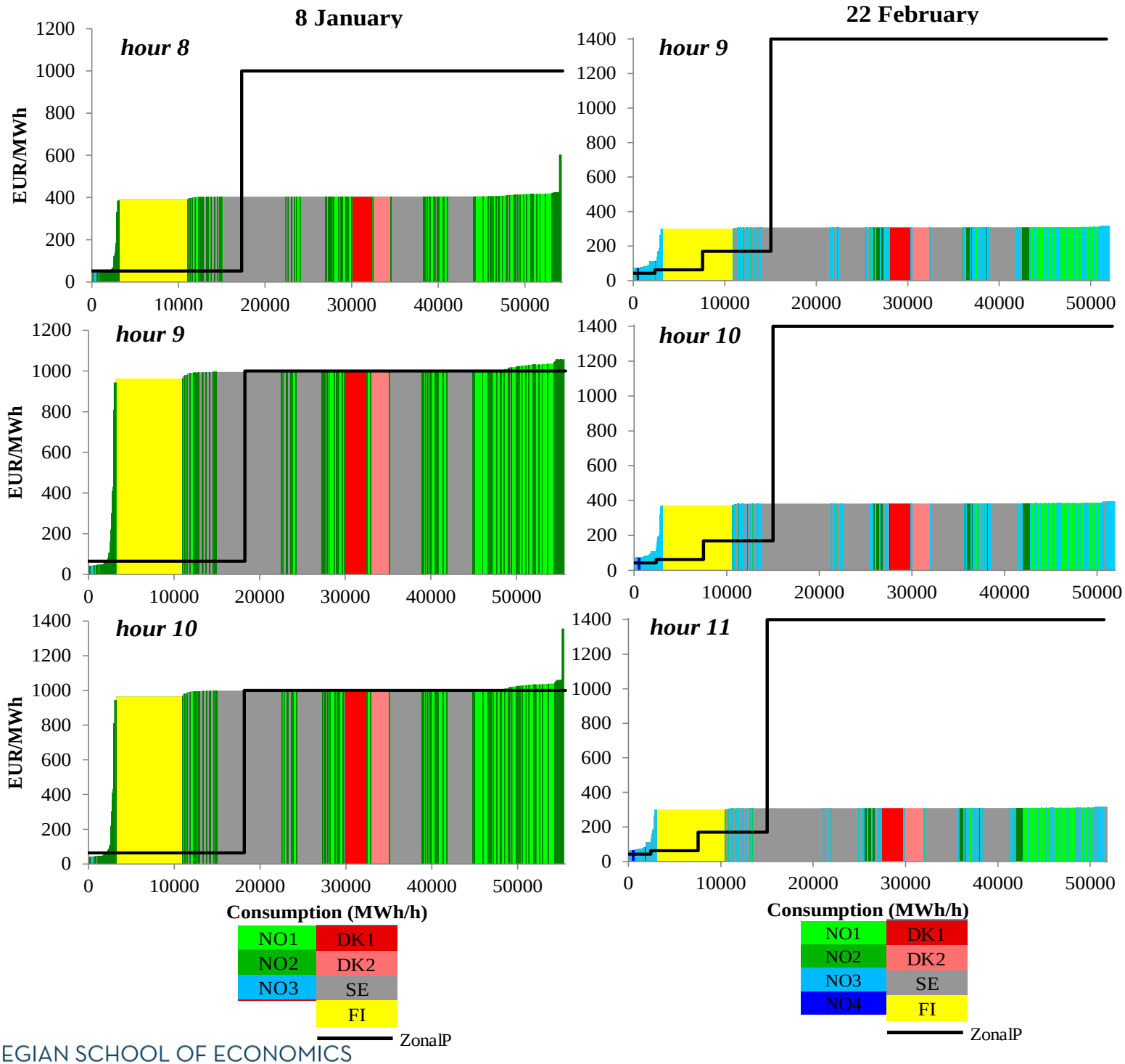


Capacity in MWh/h - 02.12.2010

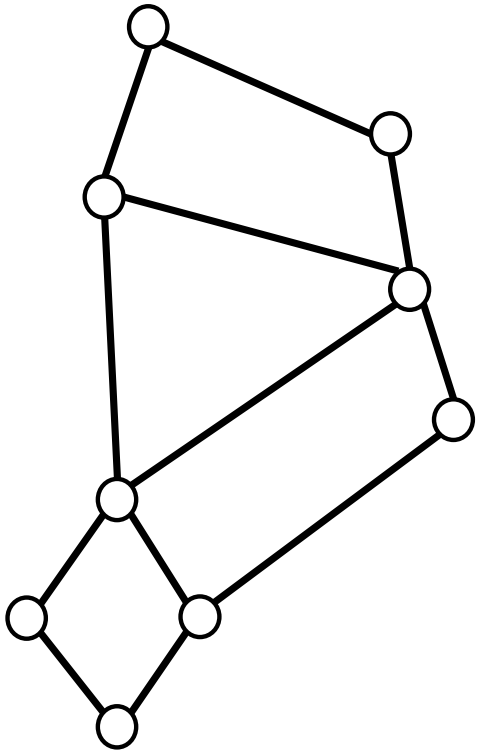
Date / Time	SE>FI	SE>DK1	SE>DK2	SE>NO1	NO1>SE	NO1>NO3	NO3>NO1	NO2>NO5	NO3>NO4	Cut 2 SE*	Cut B DK1(in)*	Cut B DK1(out)*
Max NTC	**2050**	**680**	**1300**	**2095**	**2145**	**500**	**500**	**1100**	**200**	**-**	**-**	**-**
00-01	1610	150	1300	1745	1200	150	-150	700	0	1928	1340	1320
01-02	1610	150	1300	1745	1200	150	-150	700	0	1601	1340	1320
02-03	1610	150	1300	1745	1300	150	-150	700	0	1601	1340	1320
03-04	1610	150	1300	1745	1300	150	-150	700	0	1801	1340	1320
04-05	1610	150	1300	1745	1300	150	-150	700	0	2144	1340	1320
05-06	1610	150	1200	1295	1000	100	-100	500	0	1112	1340	1320
06-07	1610	150	600	695	700	-100	100	250	0	0	1300	1320
07-08	1060	0	0	95	400	-200	200	250	0	0	1300	1320
08-09	1060	0	0	95	400	-150	150	250	0	0	1300	1320
09-10	1060	0	0	95	500	-150	150	250	0	0	1300	1320
10-11	1060	0	0	95	500	-150	150	250	0	0	1300	1320
11-12	1060	0	0	95	500	-150	150	250	0	0	1300	1320
12-13	1060	0	0	95	500	-150	150	250	0	0	1300	1320
13-14	1060	0	0	95	500	-100	100	250	0	0	1300	1320
14-15	1060	0	0	95	500	-100	100	250	0	0	1300	1320
15-16	1060	0	0	95	500	-100	100	250	0	0	1300	1320
16-17	1060	0	0	95	400	-100	100	250	0	0	1300	1320
17-18	1060	0	0	95	500	-100	100	250	0	0	1300	1320
18-19	1095	48	126	237	600	-100	100	250	0	0	1300	1320
19-20	1277	150	726	837	600	-100	100	250	0	0	1300	1320
20-21	1533	150	1300	1437	700	0	0	250	0	477	1300	1320
21-22	1610	150	1300	1745	700	50	-50	250	0	1006	1300	1320
22-23	1610	150	1300	1745	800	50	-50	500	0	2346	1300	1320
23-24	1610	150	1300	1745	800	50	-50	700	0	3897	1300	1320
Low	1060	0	0	95	400	-200	-150	250	0	0	1300	1320
High	1610	150	1300	1745	1300	150	200	700	0	3897	1340	1320
Sum	31665	1848	14352	19506	17400	-750	750	9200	0	17913	31440	31680

Data updated: 02. Dec. 2010, 13:50 Time is CET (GMT +1)

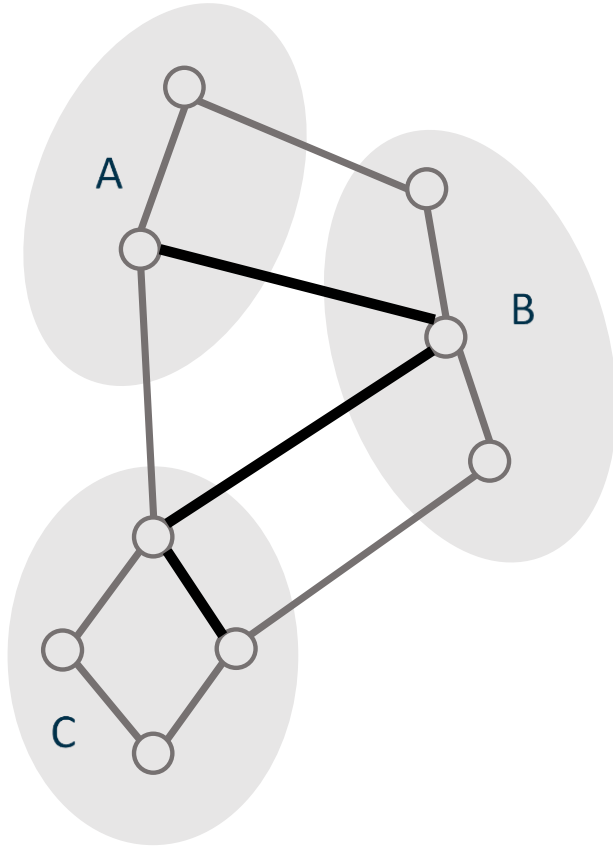
- Topology
  - Norway: Central grid; ≈170 nodes and 240 lines
  - 26 nodes in Sweden
  - Nord Pool bidding areas for the rest
- Network data from Statnett
- Bid data from Nord Pool
  - Disaggregated based on information from NVE and Statnett
- Cases
  - Single hours
  - Vary with respect to load, import / exports to / from Norway and the number of price areas
- Adjusted for imports and exports from outside the Nord Pool area


8 January
22 February
hour 8
hour 9
hour 9
hour 10
hour 10
hour 11
EUR/MWh
Consumption (MWh/h)
NO1
NO2
NO3
NO4
DK1
DK2
SE
FI
ZonalP

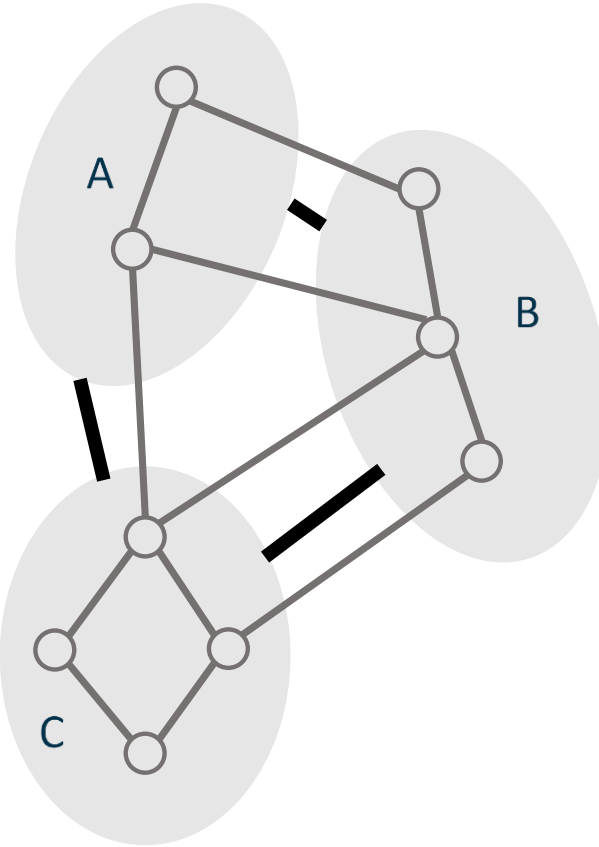
Locational pricing variants



Nodal FB model



Zonal FB model



ATC model

FBMC – Generation shift keys (GSKs)

- A GSK gives the change in net injection at a node relative to a change in the net position of the zone it belongs to
- Is determined before market clearing, but cannot be known accurately until after
- TSOs calculate GSKs by using a Base Case, anticipating grid topology, net positions, and corresponding power flows for each hour of the day of delivery
- We define GSKs as the nodal weight of the net position within each zone:

$$gsk_{i,z} = \frac{Q_i^s - Q_i^d}{\sum_{i \in N_z}(Q_i^s - Q_i^d)}, \forall i, z, i \in N_z$$

- The GSKs cannot be defined in a balanced pricing area, i.e. where

$$\sum_{i \in Z}(Q_i^{s*} - Q_i^{d*}) = 0$$

FBMC – Zonal PTDFs

- TSOs use GSKs and nodal PTDF matrices to calculate zonal PTDF matrices
- Zonal PTDF matrices are used to estimate the influence of the net position of any zone on the lines in the FBMC model

$$zptdf_{l,z} = \sum_{i \in N_z} nptdf_{l,i} * gsk_{i,z}, \forall l \in L$$

$$zptdf_l^{z,zz} = zptdf_{l,z} - zptdf_{l,zz}$$

- In the nodal model physical limitations are typically applied to the whole network
- In the FBMC model physical restrictions are imposed on the selected critical branches (CBs)

FBMC – Critical branches (CBs)

- A CB is a transmission line that is significantly impacted by cross-border trading
  - In CWE a transmission line is critical if its maximum zone-to-zone PTDF is larger than a fixed threshold value
- The TSOs publish CBs and their corresponding Remaining Available Margin (RAM) before market clearing

FBMC – Remaining Available Margin (RAM)

- The RAM is the line capacity that can be used by the day-ahead market, and is calculated as

$$ram_l = cap_l - F_l'$$

- where cap_l is the thermal capacity limit and F_l' includes:
  - flows caused by transactions outside the day-ahead market, e.g. re-dispatching, bilateral trades, forward market,…
  - an adjustment value based on TSO knowledge, and
  - a safety margin that is needed to compensate for the approximations and simplifications made by the FBMC model
- For simplicity we assume $ram_l = cap_l$

Zonal pricing – Flow based market coupling (FBMC)

$$\max \sum_i \int_0^{Q_i^d} P_i^d(Q)dQ - \int_0^{Q_i^s} P_i^s(Q)dQ \quad (1)$$

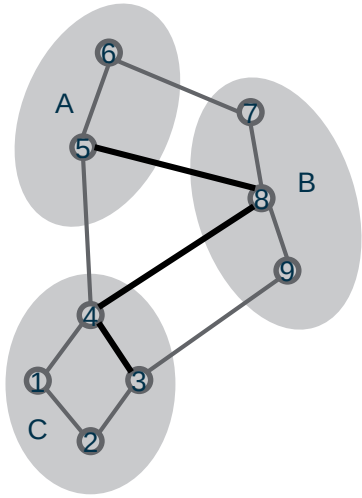
Subject to:

$$NEX_z = \sum_{i \in N_z} (Q_i^s - Q_i^d), \forall z \in Z \quad (2)$$

$$\sum_{z \in Z} NEX_z = 0 \quad (3)$$

$$FL_l{}^{FBMC} = \sum_z zptdf_{l,z} * NEX_z, \forall l \in CB \quad (4)$$

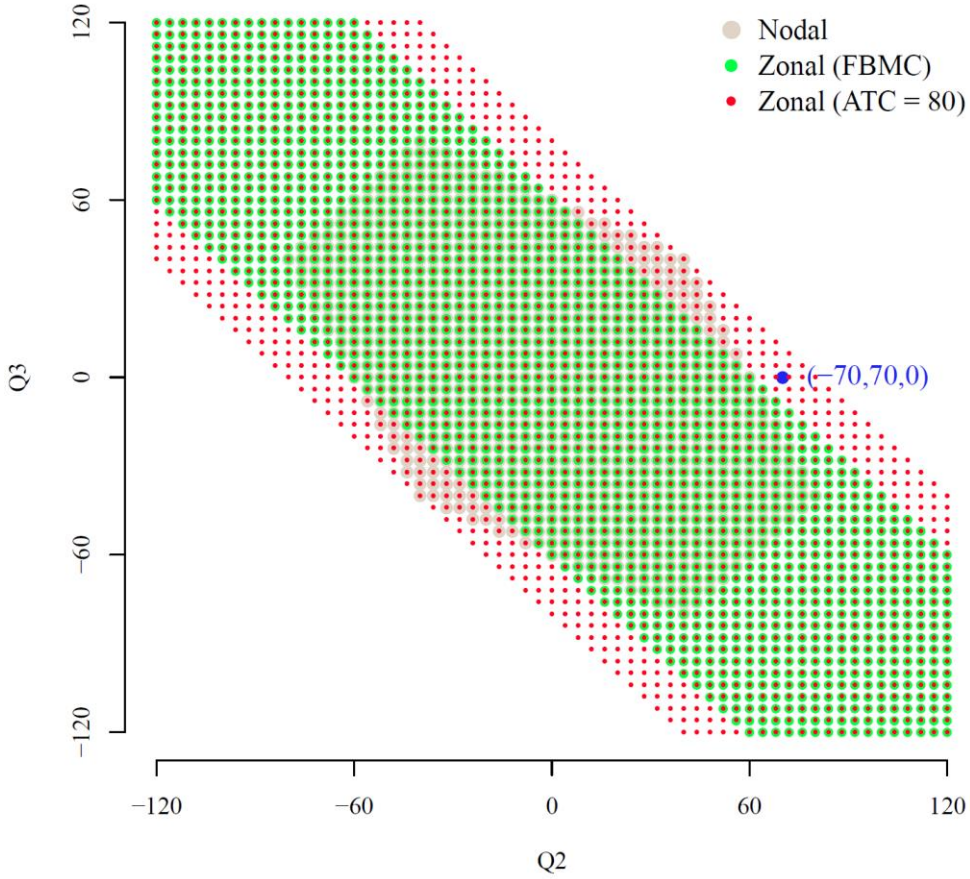
$$\left|FL_l{}^{FBMC}\right| \leq cap_l, \forall l \in CB \quad (5)$$

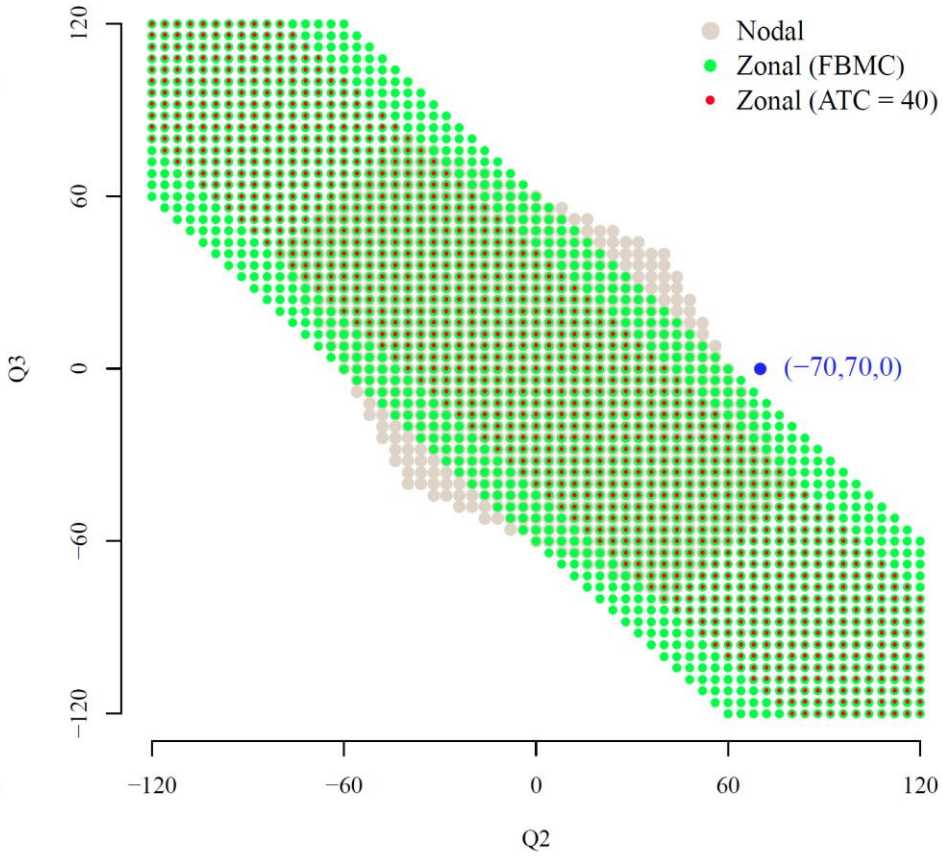


Nodal pricing versus FBMC

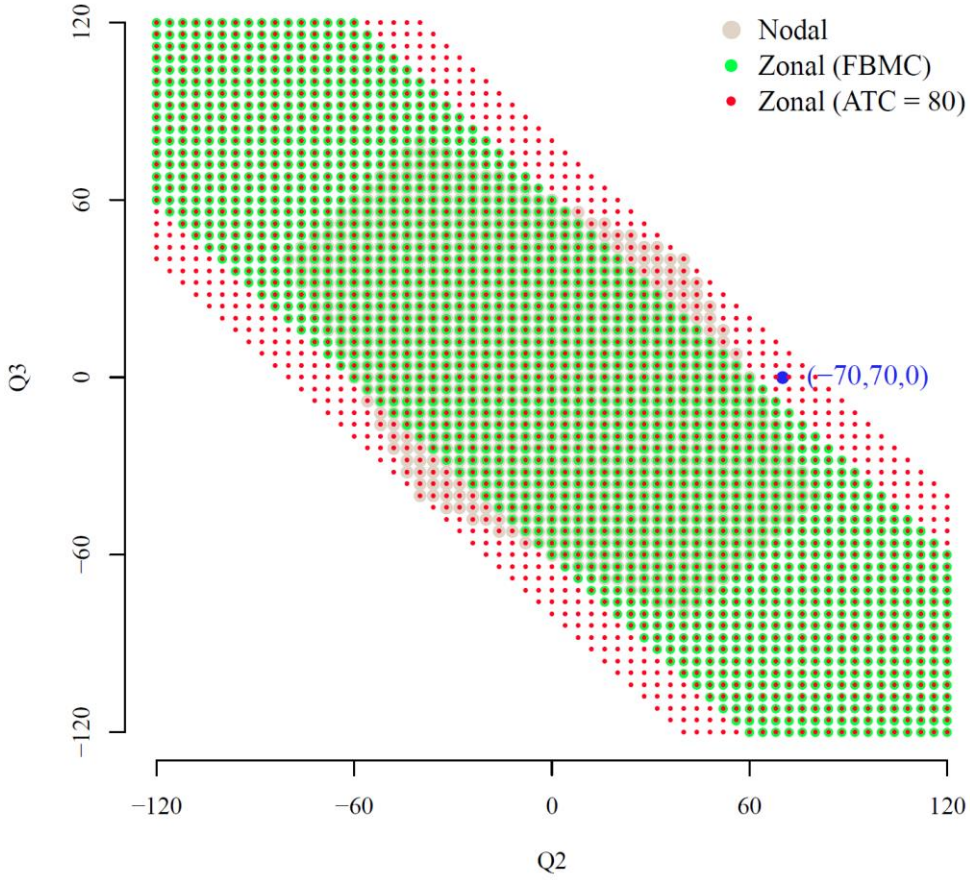
- If the base case that defines the GSKs is feasible in the nodal model, it is also feasible in the FBMC model
- If the optimal nodal price solution is used to set GSKs, then the optimal nodal price solution is feasible in FBMC and the objective function value is ≥ the objective function value of the nodal price solution
- The FBMC solution might not be feasible in the original problem implying a need for re-dispatching
- A lot of discretion
  - Generation shift keys, GSKs
  - Critical branches, CBs
  - Capacity on critical branches, RAM

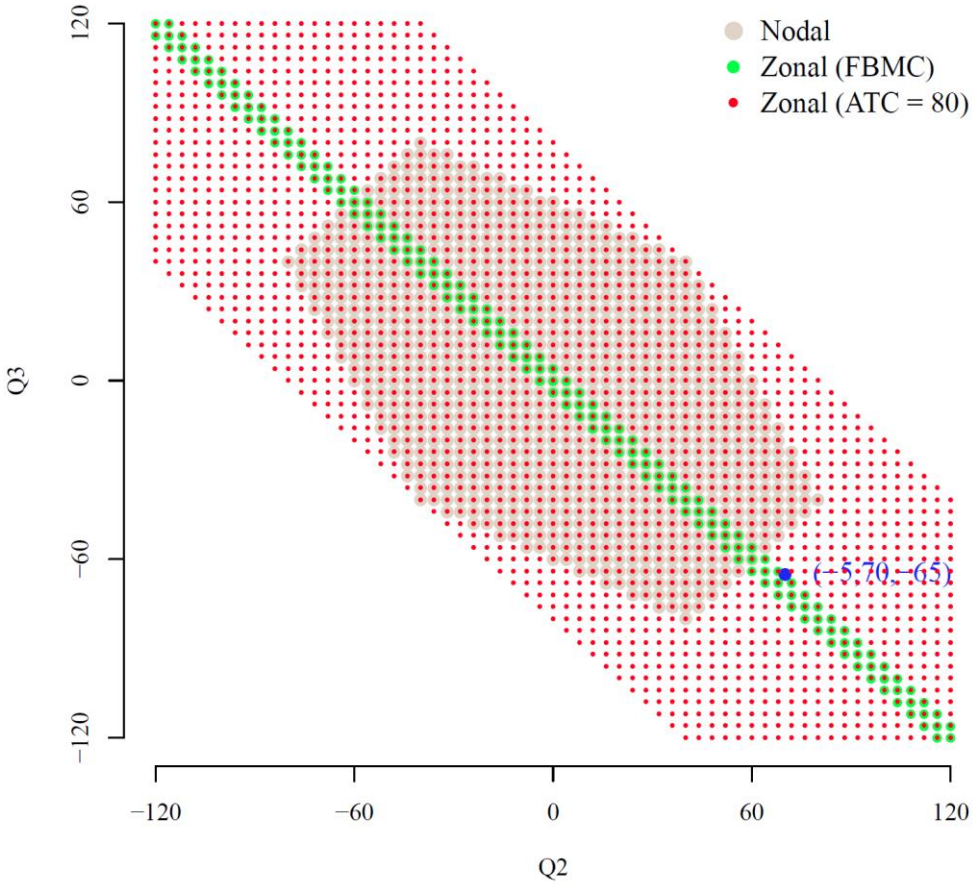
Feasible area



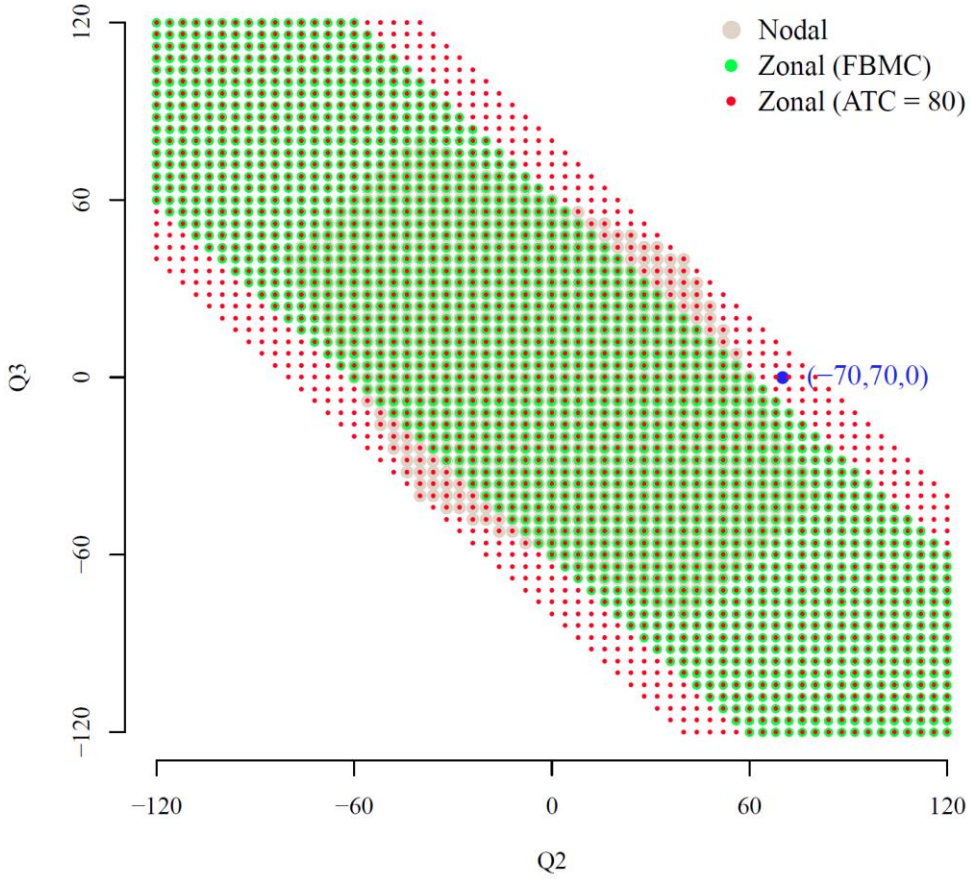


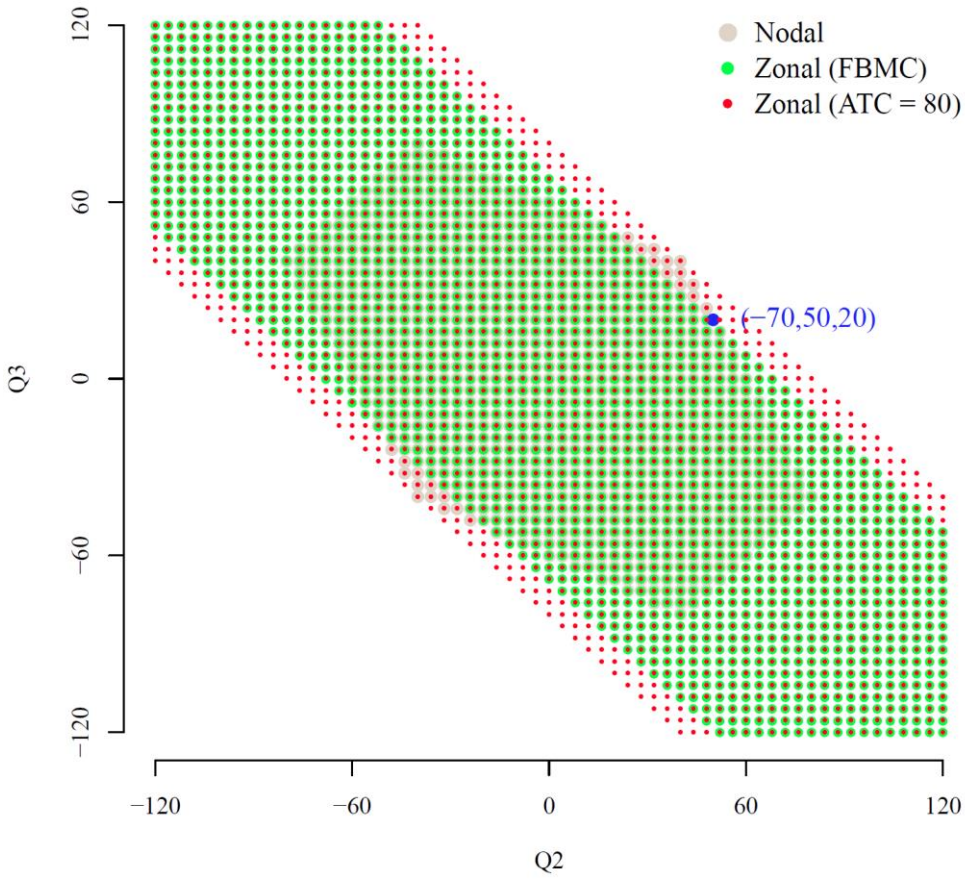
Feasible area





Feasible area



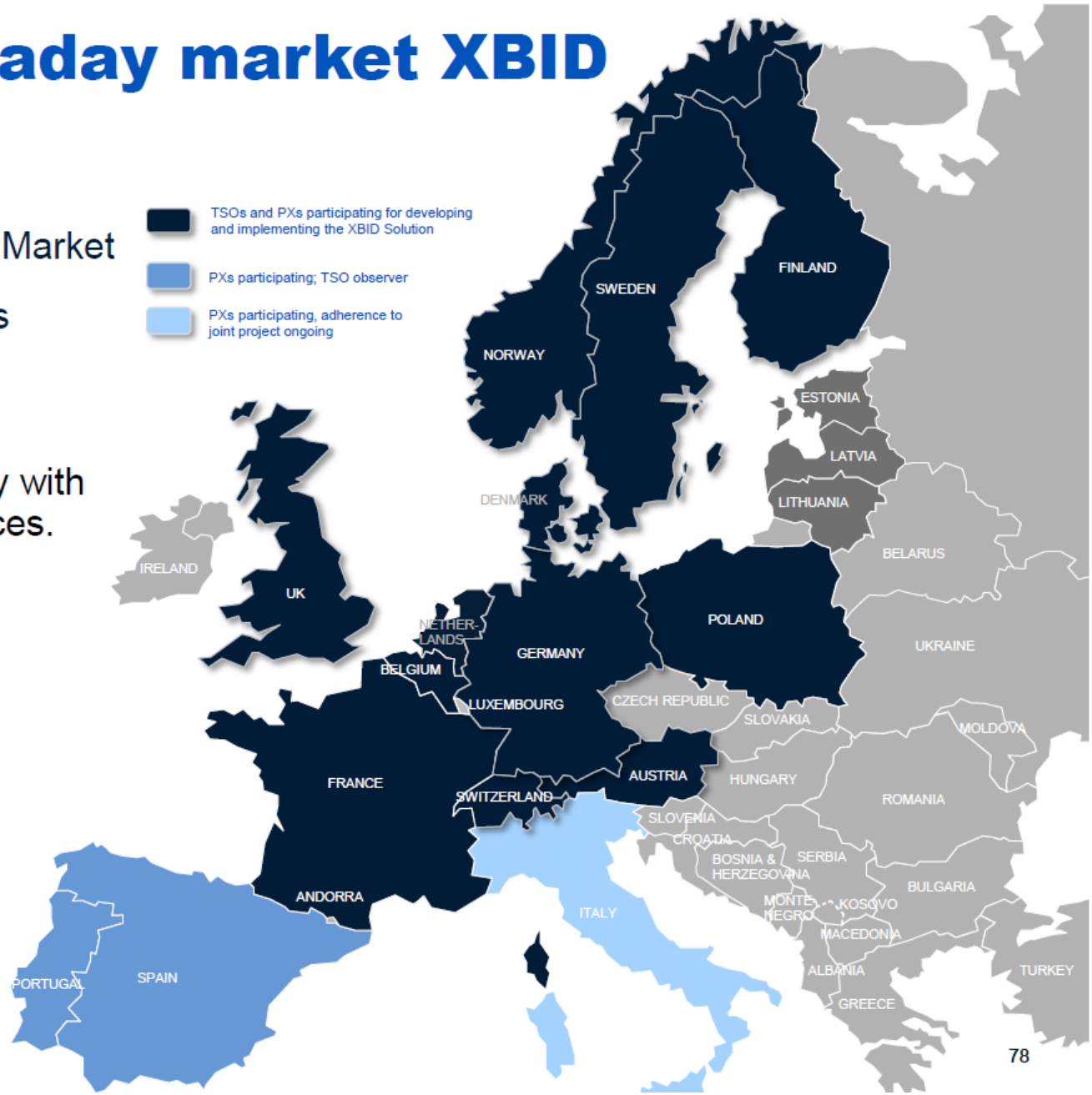


Conclusions

- The European market coupling model prices power in large regions
- Many important operational details are omitted
- Not necessarily clear that FBMC model is an improvement, neither when it comes to efficiency nor transparency
- Still many choices that affect prices in own and other regions (GSKs, CBs, RAM)

One common Intraday market XBID

- EU target model for a Common European Cross-Border Intraday Market
- 4 Power exchanges and 17 TSOs
- Central matching engine
- PXs competing across geography with own front end systems and services.
- Go live target date: Q1 2018



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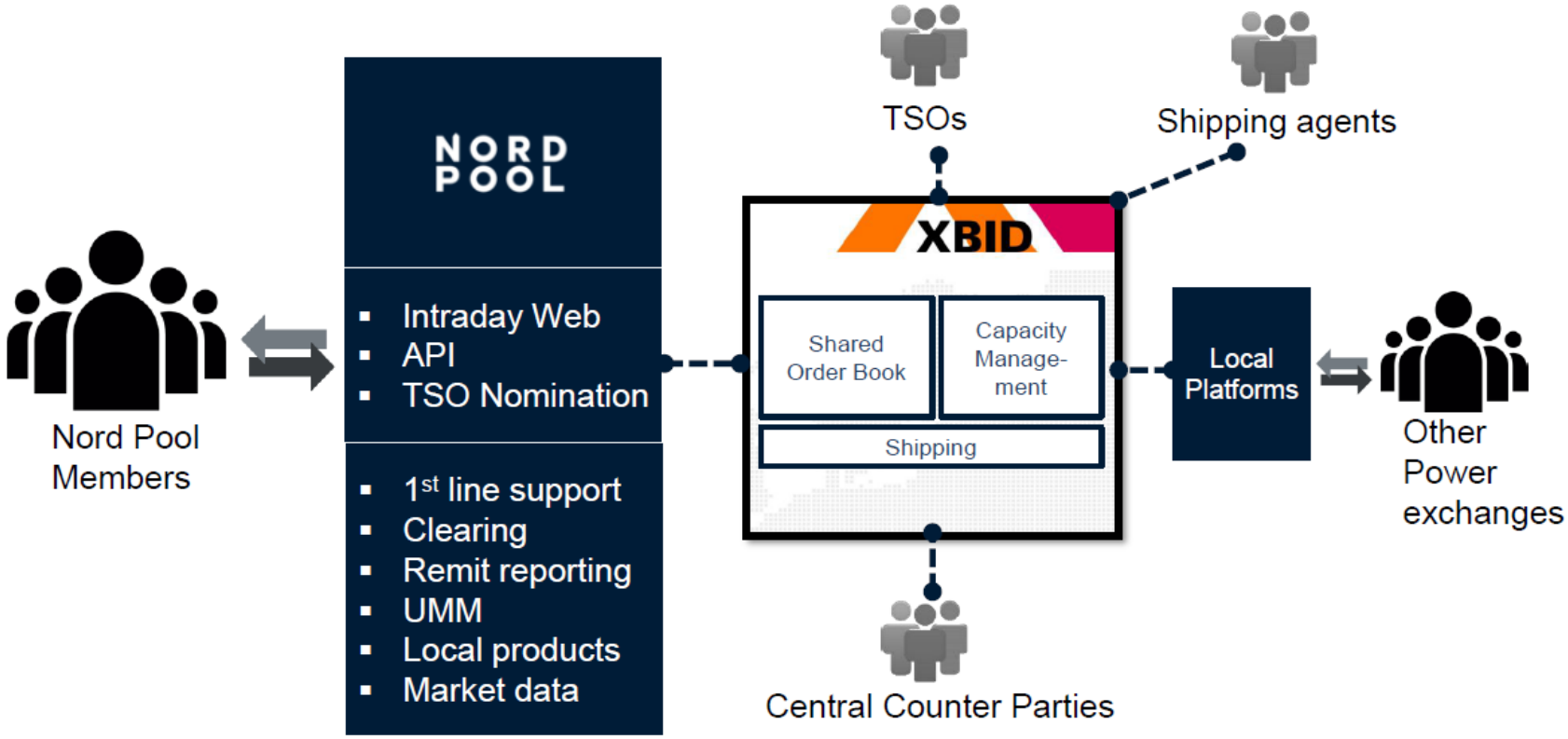
XBID operating model



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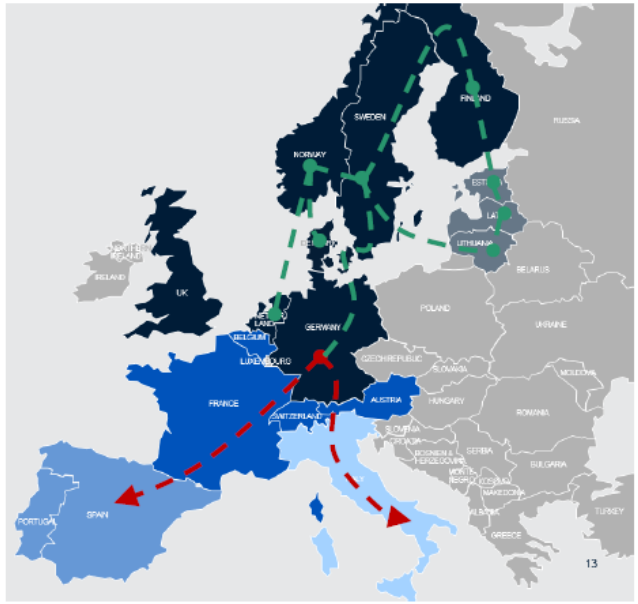
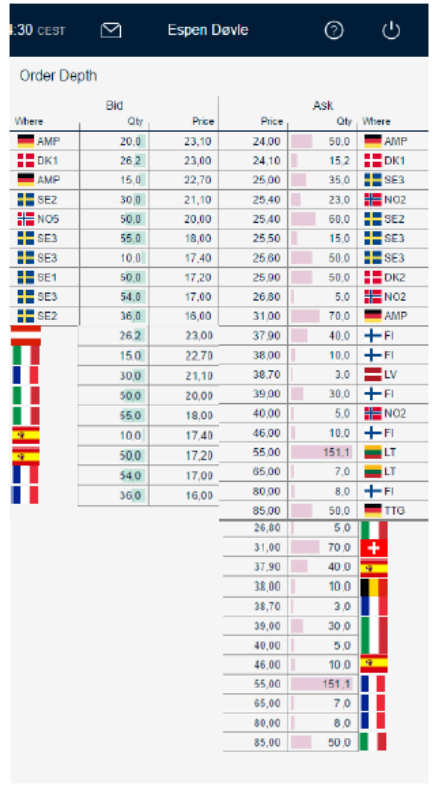
How will XBID affect the Nordic market participants?

Shared orderbook



Improved liquidity



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