Locational Pricing in the Nordic Electricity Market

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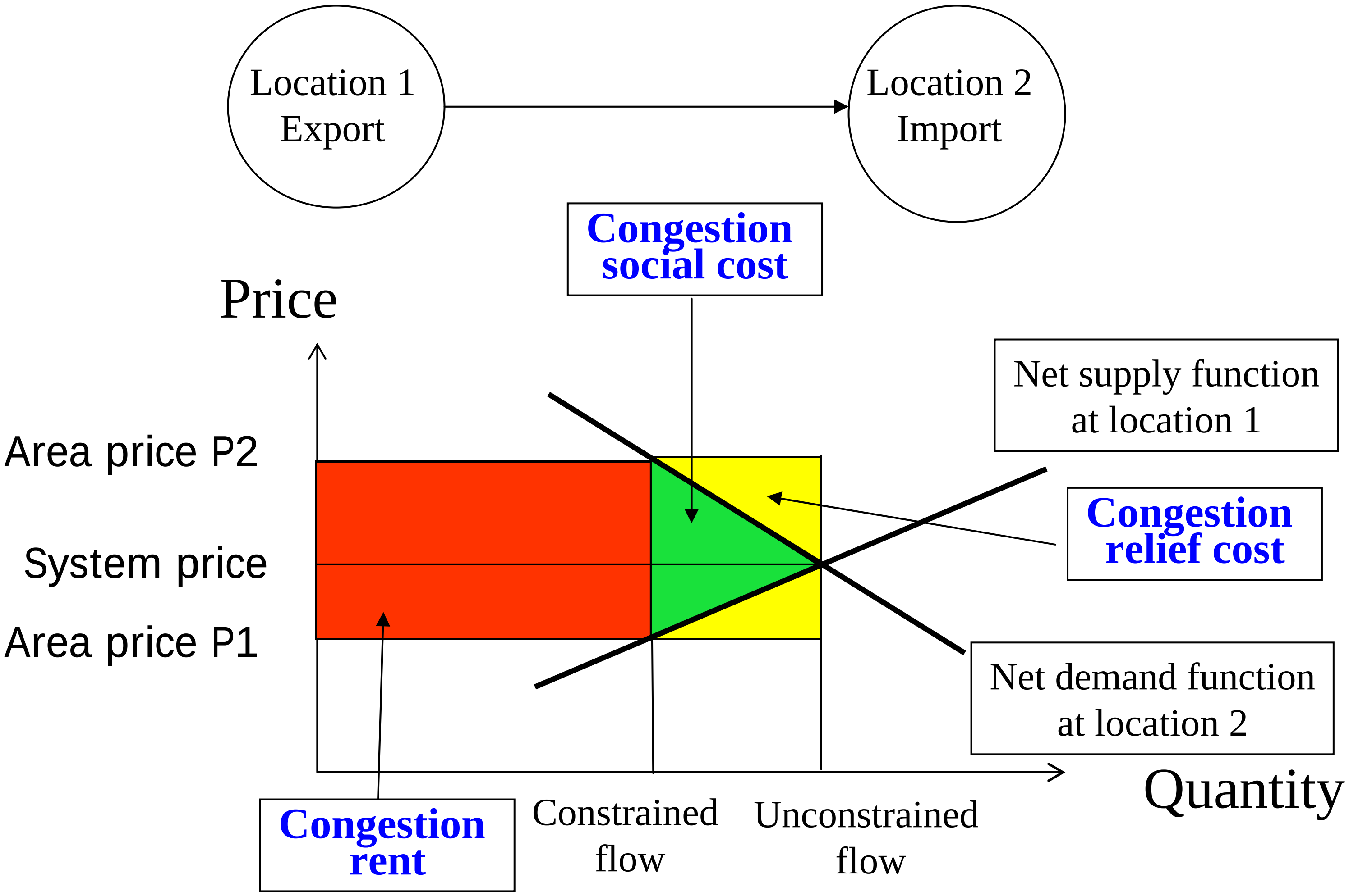
Congestion Management

- 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
    - Benchmark
- Alternative methods to realize optimal dispatch
  - Nodal prices, Flowgate prices, Optimal redispatch…
- Provide price signals
  - For efficient use of the transmission system
  - For transmission, generation and load upgrades

Measures of Congestion Cost

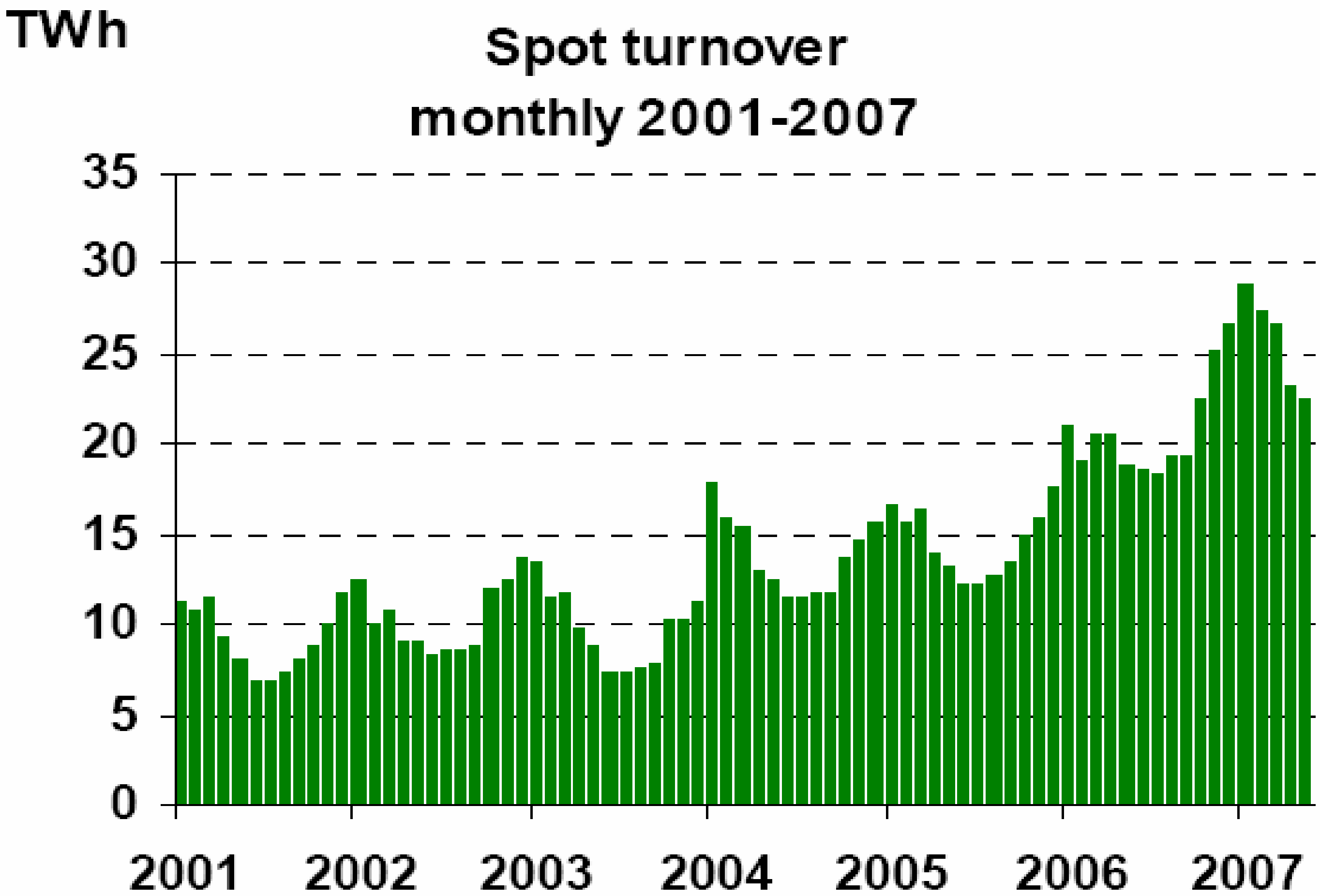


Nord Pool Spot

- Covers
  - Norway, Sweden, Finland, Denmark, Kontek
- Day-ahead
  - Supplemented by balancing / regulation markets
- Voluntary pool
  - Trades between Elspot areas
  - Agents that use Nord Pool Spot in order to determine prices and as a counterpart
- Three kinds of bids
  - Hourly bids – bids for individual hours
  - Block bids – create dependency between hours
  - Flexible hourly bids – sell during hours with highest prices

Volumes

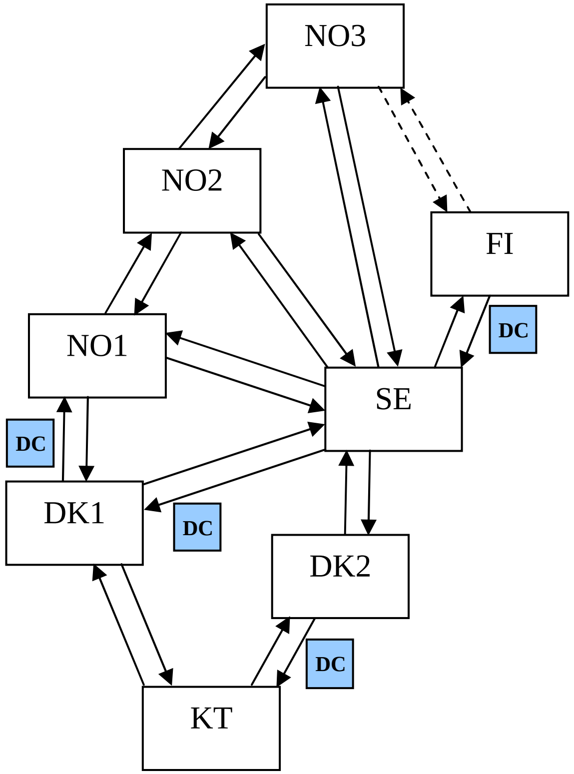
- 70-80 % of physical power is traded at Nord Pool



Network model SESAM

- 8 nodes
- Direction dependent capacities
- AC/DC treated equally
- No loop flow modeling

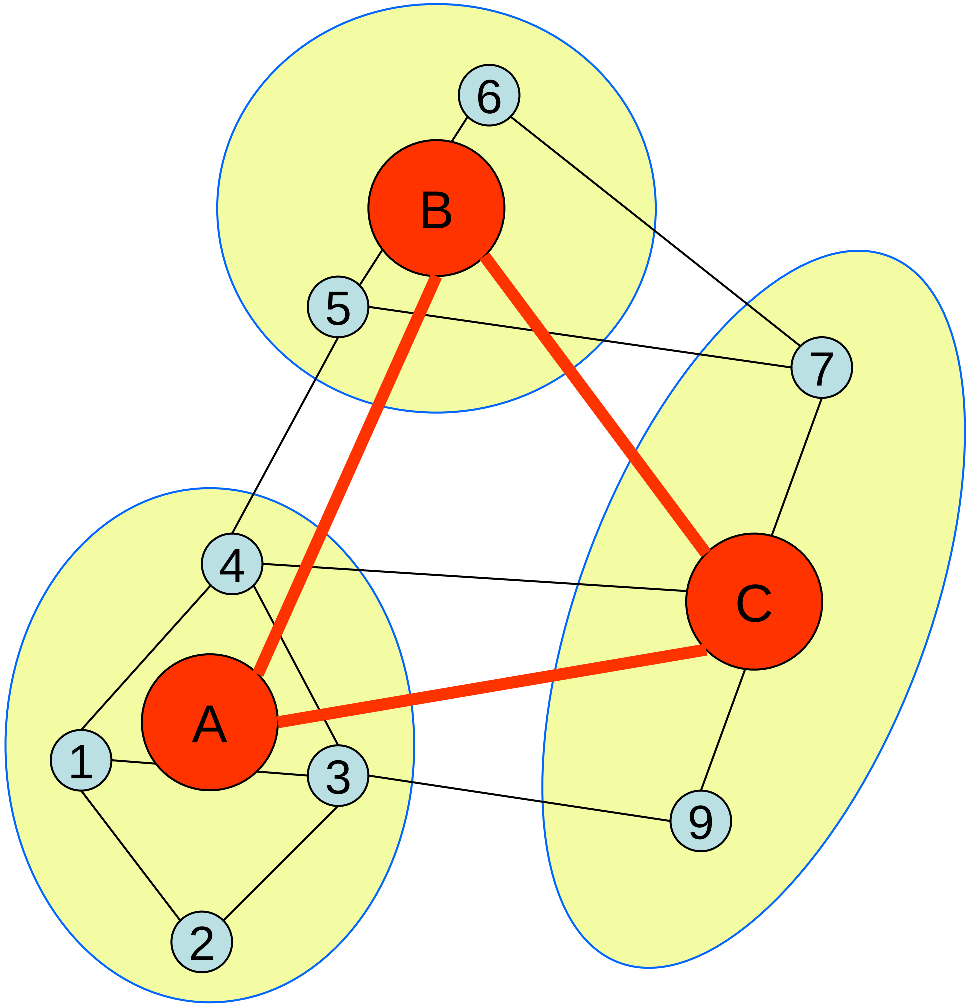
Norway can be split further into more zones if necessary



Congestion Management in the Nordic Power Market

- Two methods coexist:
- Inter zonal congestion – Zonal pricing / Market splitting
  - Day-ahead market
  - For the largest and long-lasting congestions in Norway and for congestions on the borders of the control areas
- Intra zonal congestion – Counter trading / Redispatching
  - For constraints internal to the price-areas
  - For real-time balancing
    - The regulation market

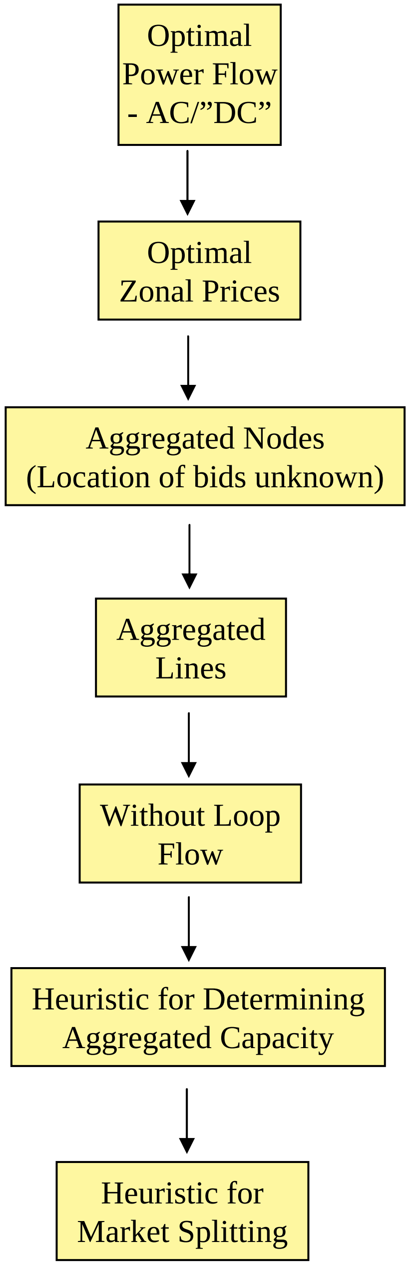
Aggregation – Example



True network
- ”All” nodes included
- ”All” lines represented

Economic aggregation
- ”All” nodes included
- ”All” lines represented
- Zones with uniform prices

Physical aggregation
- Aggregate nodes
- Aggregate lines



I: Theoretical benchmark:
"DC" is an approximation of the full alternate current (AC) power flows

II: Require the same prices in several nodes:
A restriction / More constrained model

III: Intra-zonal constraints are not taken into account:
Relaxation / Less restrictive model

IV: Capacities are added on aggregated lines:
Relaxation / Less restrictive model

V: Characteristics of electrical power flows are not considered:
Relaxation / Less restrictive model

VI: Restrictions added in order to obtain feasible solution in the original problem

VII: The old trading system, SAPRI, computes prices from sequentially splitting the system in two parts
SESAM is optimization based and solves this approximation

Physical Aggregation in Relation to OPF-Benchmark

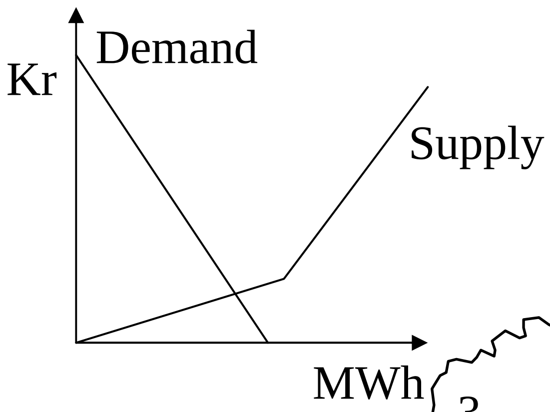
- Issues for evaluating performance
  - The number of zones used
  - The definition of the areas
  - Fixed of flexible zones
  - How to deal with internal constraints
  - Uncertainty about the location of bids within zones
  - How to determine capacity on aggregated lines
  - Aggregate flow model without Kirchhoff’s laws
  - Heuristic procedure for market splitting
  - How to deal with block bids and flexible hourly bids

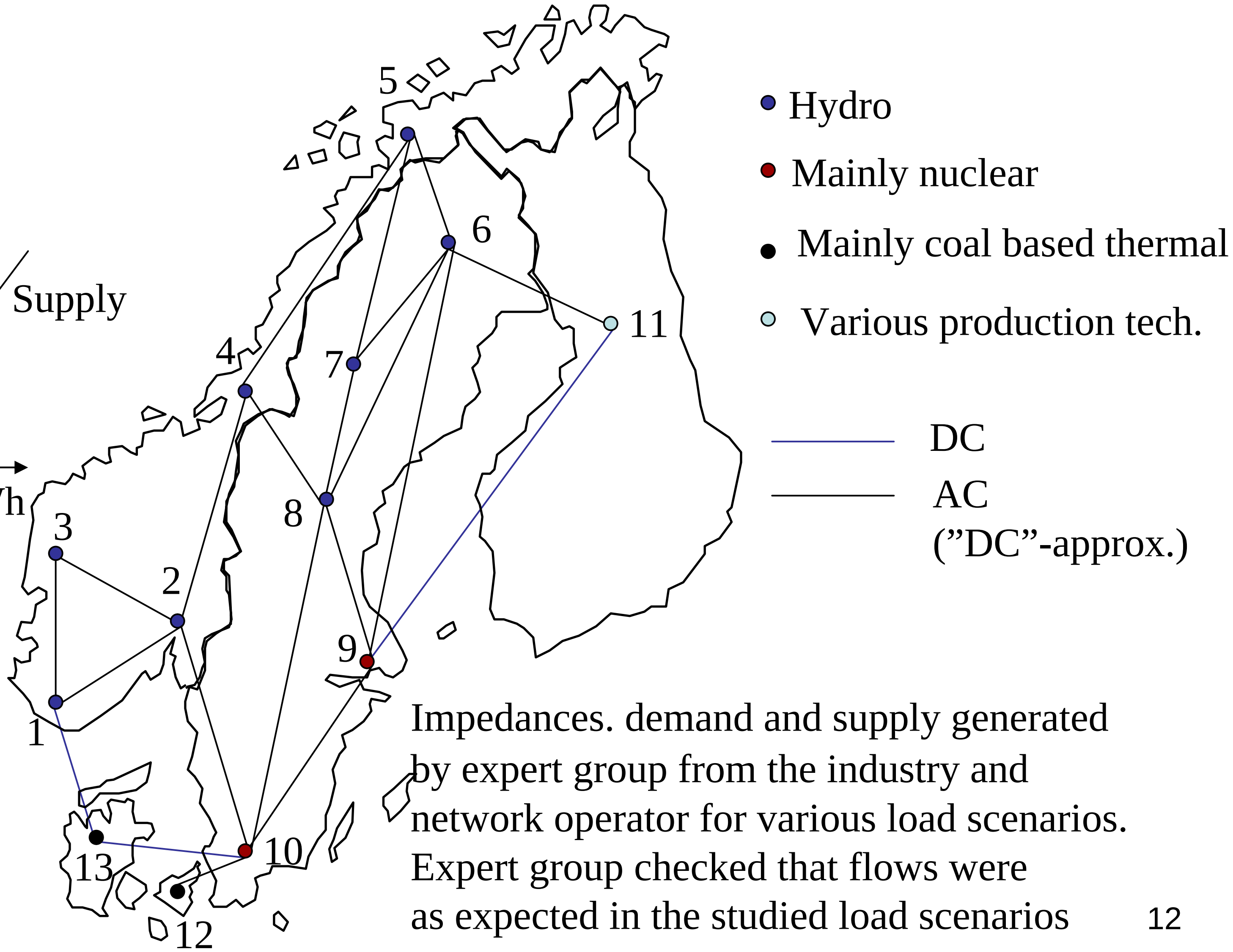
2 Projects

- EBL project 2001
  - What are the potential for cost savings from different zone definitions?
  - What is the cost of moving inter zonal bottlenecks to zonal borders?
- NVE project 2005-2007
  - How is congestion handled at Nord Pool, consequences and alternatives for improvement

Model of the Nordic Power System

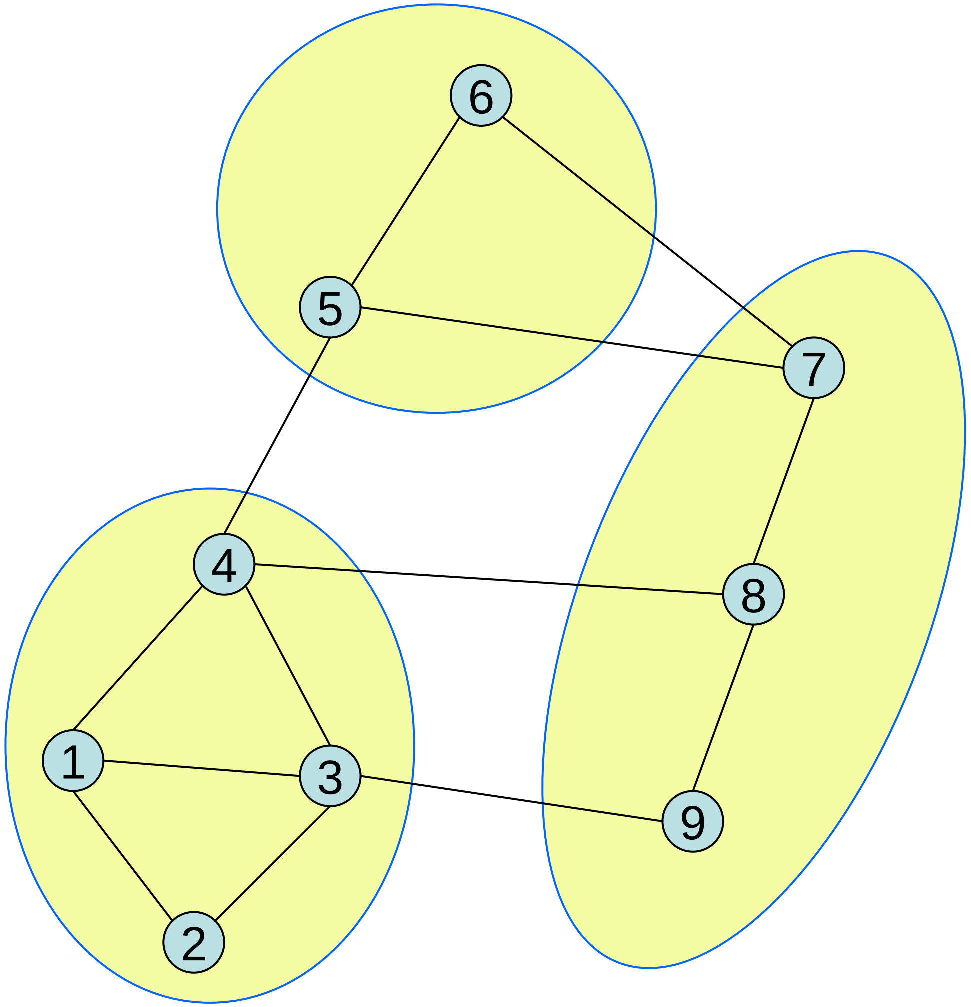
For every node:





Impedances. demand and supply generated by expert group from the industry and network operator for various load scenarios. Expert group checked that flows were as expected in the studied load scenarios

Optimal Zonal Prices



- "Economic aggregation"
- Other assumptions
  - No market power
  - Water values reflected in supply curves

Main Results

- The differences in congestion costs can be substantial between different zone allocations
  - Optimal handling of capacity limitations can reduce bottleneck costs considerably
- The more zones the better results, but need not always have many zones to reach a near optimal solution
- Without flexible price areas
  - Important to have enough fixed price areas in order to deal with special situations due to inflows and load

Transfer Capacities

- Capacity limits are determined by TSOs and communicated to Nord Pool before market clearing
- Limits are based on
  - Forecasts of supply and demand
  - Imports/exports from the Nord Pool area
  - Security constraints
- Sweden cut 2 / Denmark DK1 cut B
  - Proportional allocation to each connection
  - Optimization routine to determine capacity utilization

Source: Statnett

Elspotutveksling og handelskapasitet

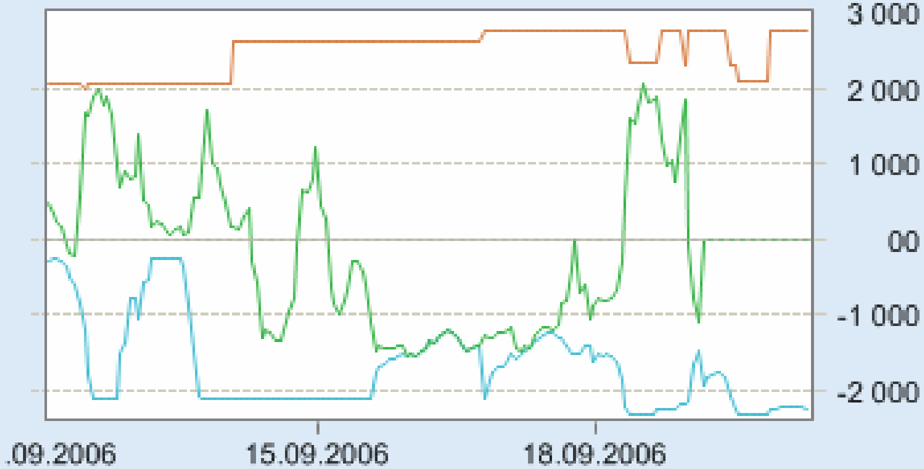
Grafen viser øvre (brun) og nedre (blå) grense for handelskapasitet pr. elspotområde, samt faktisk utveksling for det enkelte området(grønn).

Elspotområdene NO1 og NO2 er nå delt mellom 300kV Øvre Vinstra - Vågåmo, 123 kV samleskinne Litjfossen og 123 kV samleskinne Åskåra.

Alle målinger skjer pr. time. Velger du en annen målefrekvens, vises gjennomsnittlig timeverdi. For eksempel viser grafen når du velger målefrekvensen "dag" et gjennomsnitt av timene for hver dag.

Velg visningsmodus ◉ Graf ○ Tabell

Elspotutveksling NO1 i MWh/h



Importkapasitet

Høyeste:	-270 MWh/h
Laveste:	-2 320 MWh/h
Sum:	-284 691 MWh

Eksportkapasitet

Høyeste:	2 750 MWh/h
Laveste:	1 980 MWh/h
Sum:	416 293 MWh

Elspot-utveksling

Høyeste:	2 053 MWh/h
Laveste:	-1 575 MWh/h
Sum:	-30 850 MWh

Målefrekvens: Timer

Tidsperiode: En uke

Velg elspotområde:

◉ Elspot NO1

○ Elspot NO2

Main Results

- That two congestion methods are used in the Nordic power market may lead to less efficient capacity usage and larger price differences than necessary
  - ”Moving” an internal bottleneck to a zonal border can be very costly
- Example:
  1) All capacity limitations are considered at their true values, i.e. $C_{2\text{-}3}$ = 2 800 MW and $C_{2\text{-}10}$ = 2 000 MW
  2) The capacity limit on line 2-3 is not considered, instead the capacity on line 2-10 is reduced to 940 MW, which induces flow over line 2-3 to fall below the capacity limit of 2 800 MW

Cost of bottleneck	**ULF**	**OLF**	**SYS**	**NOR2**	**NOR5**	**N2S2**	**NS3**	**N3S3**	**N5**	**N6**
1)	0	162	224	219	186	195	199	170	171	170
2)	0	353	436	435	434	371	390	355	401	355
DIFF		**118 %**	**95 %**	**99 %**	**133 %**	**90 %**	**96 %**	**109 %**	**135 %**	**109 %**

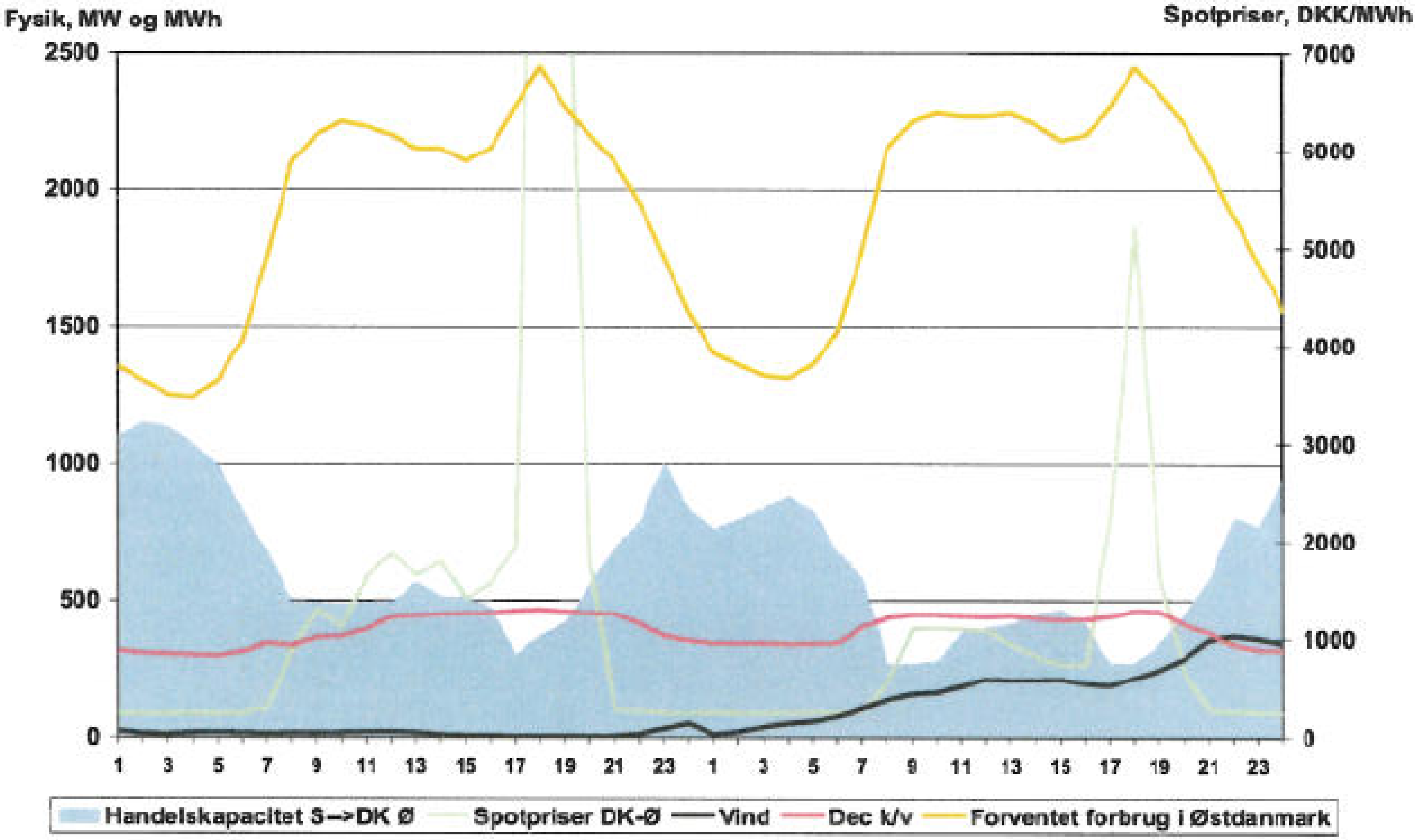
Different Price Vectors

Node	Optimal nodal prices			Optimal zonal prices		
	ULF	**OLF 1)**	**OLF 2)**	**NOR2**	**NOR5**	**N3S3**
1	147.65	118.61	87.39	137.06	121.10	99.17
2	147.65	151.63	87.39	137.06	156.72	158.99
3	147.65	85.58	87.39	137.06	85.48	99.17
4	147.65	127.91	97.47	105.55	119.84	110.04
5	147.65	92.35	91.41	105.55	79.12	110.04
6	147.64	174.41	159.62	170.75	169.10	146.32
7	147.65	135.50	141.88	170.75	169.10	146.32
8	147.65	139.75	174.61	170.75	169.10	146.32
9	147.65	174.41	202.08	170.75	169.10	175.88
10	147.65	203.94	272.01	170.75	169.10	204.82
11	147.65	174.41	159.62	170.37	169.53	175.88
12	147.65	203.94	272.00	242.60	232.02	204.82
13	147.65	203.94	250.56	242.60	232.02	204.82

Do Bottlenecks ”Move”?

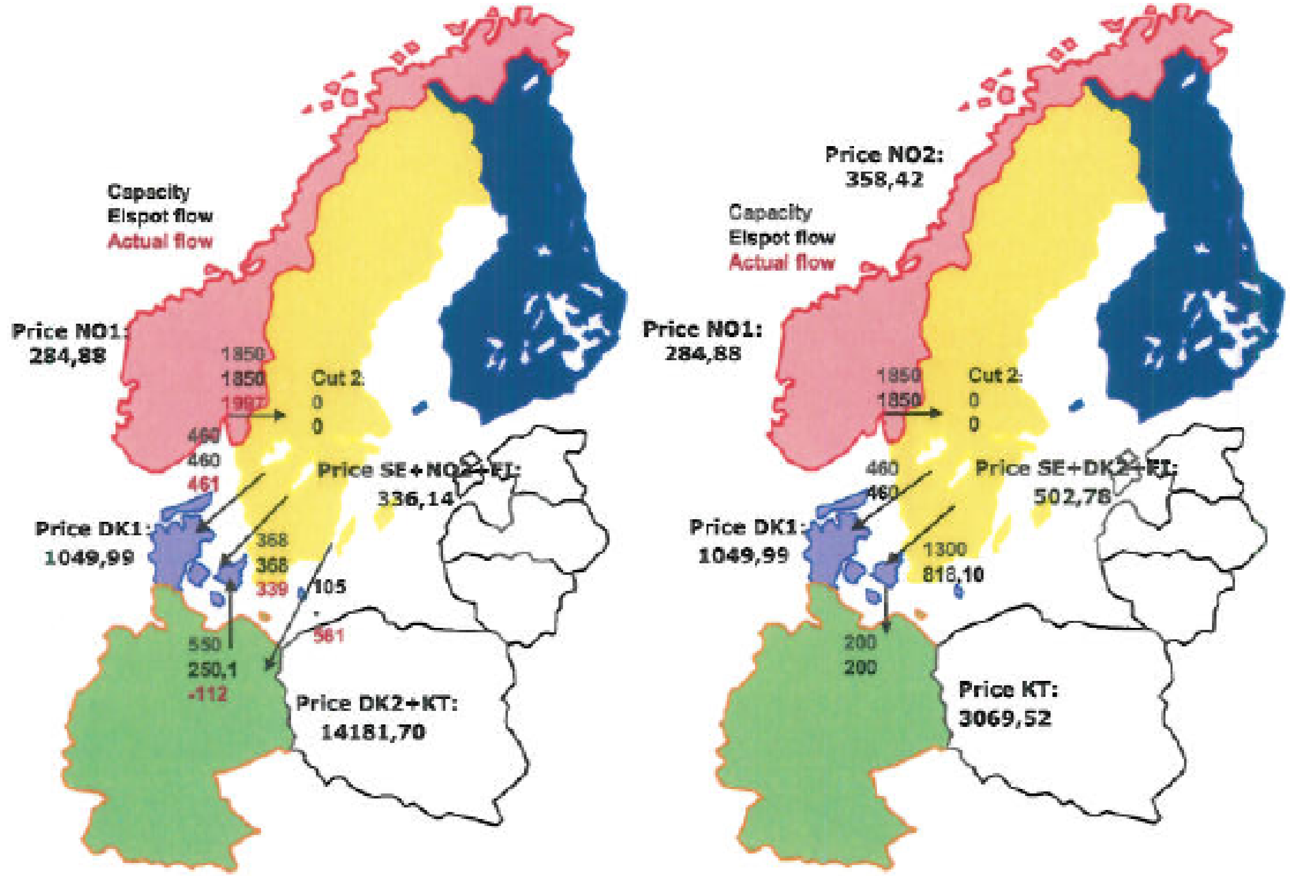
- ”The bottleneck from the west towards Oslo is handled through export limitations to Sweden. In Sweden and on Jylland and Själland counter purchasing is used after a reduction of import/export has been made.” Nordel Maj 2002

Ulrik Møller: ”Redegørelse for prisdannelsen i november 2005 i Østdanmark.” Dokument nr. 244051. Energinet.dk



Figur 3: Diverse fysiske forhold og spotpris i Østdanmark d. 28.og 29. november.

Nord Pool Spot har udført en række alternative prisberegninger af time 18 den 28. november 2005. Figur 10 viser effekten af fuldkapacitet på Øresundsforbindelsen.



Area	Price Change
NO2	+20
SE+FI	+170
DK2	-13 500
KT	-11 000

Figur 10: Venstre figur: Realiserede spotpriser og flow time 18, 28. november 2005. Højre figur: Elspot simulerede spotpriser med fuld kapacitet på Øresundsforbindelsen. Priser er i NOK/MWh
Note: forskellen i Elspot flow og Actual flow i venstre figur på Kontek-forbindelsen, skyldes Energi E2s gamle aftale om at sende 350 MWh i sydgående retning.

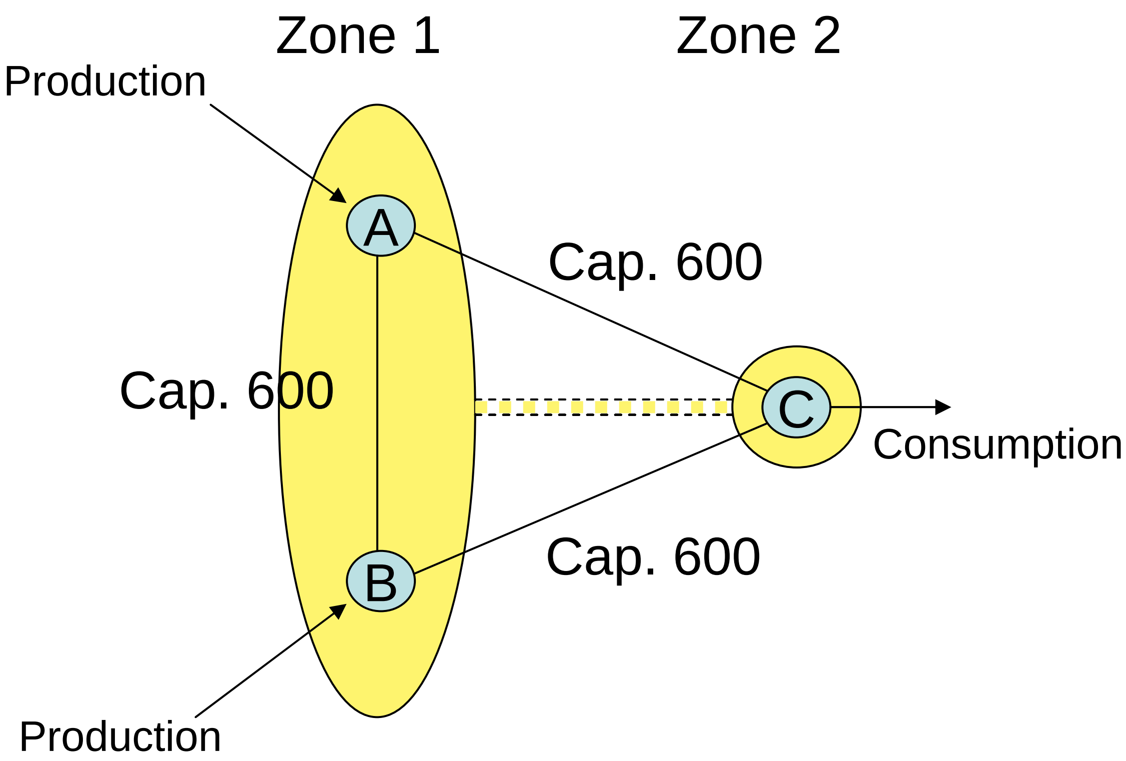
NVE Weekly Report April 14 2004

”*..The price differences between Norway and Sweden have been considerable and more than 10 øre/kWh during several hours. For many of these hours Svenska Kraftnät has limited the export capacity from Sweden to southern Norway. Given full utilization of capacity between Sweden and NO1 during the hours with price differences, this practice may have contributed to an import reduction of 227 GWh. In total for the first 15 weeks this approach results in an import reduction of more than 970 GWh.”*

Other Issues

- Is it necessary to model ”loop flow”?
  - Does it depend on the level of aggregation?
  - How to do it?
- How is the capacity of an aggregated line to be determined?
  - A cut may consist of several individual lines
  - Flows in opposite directions
- How important is it to get bids on nodal level?
  - Uncertainty about the location of bids within zones
  - Inexact capacity determination and -control as a result of that
  - Need to hedge for ”worst case” location of bids?

Example



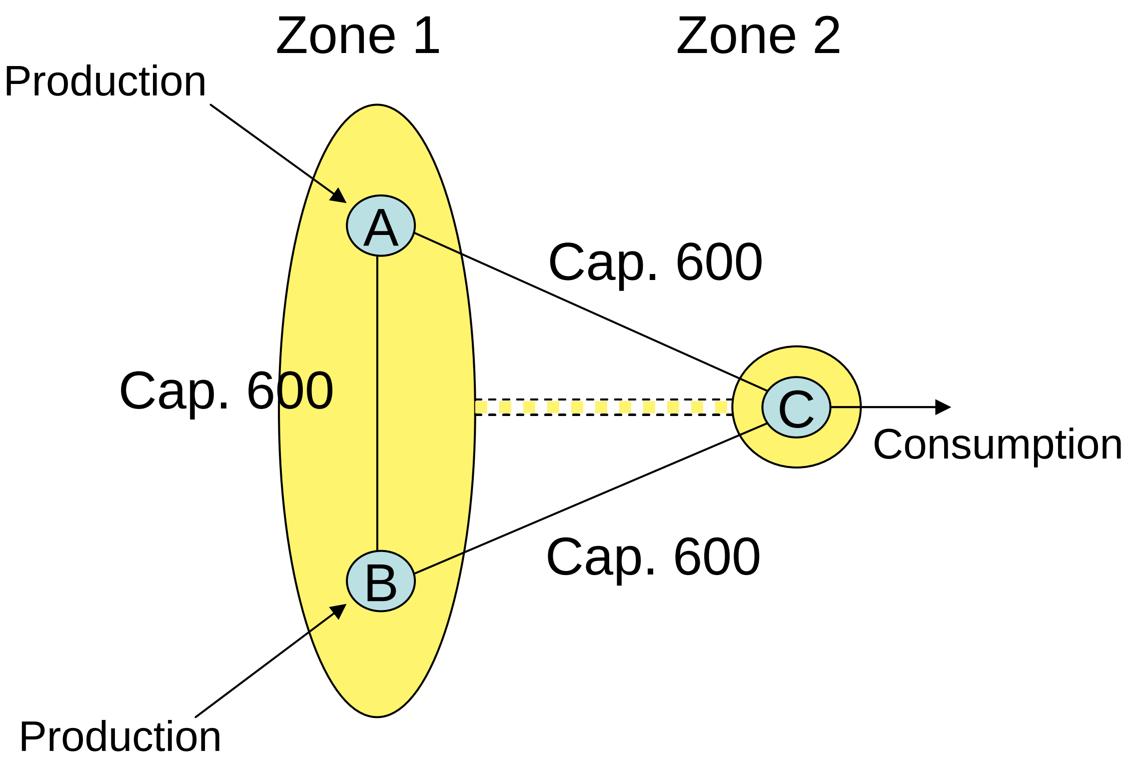
$f_{AC} = 2/3\ q_A + 1/3\ q_B$

$f_{BC} = 1/3\ q_A + 2/3 q_B$

$f_{AB} = 1/3\ q_A - 1/3\ q_B$

Which capacity to choose for the aggregated link between zone 1 and zone 2?

Example



f_{AC} = 2/3 q_A + 1/3 q_B

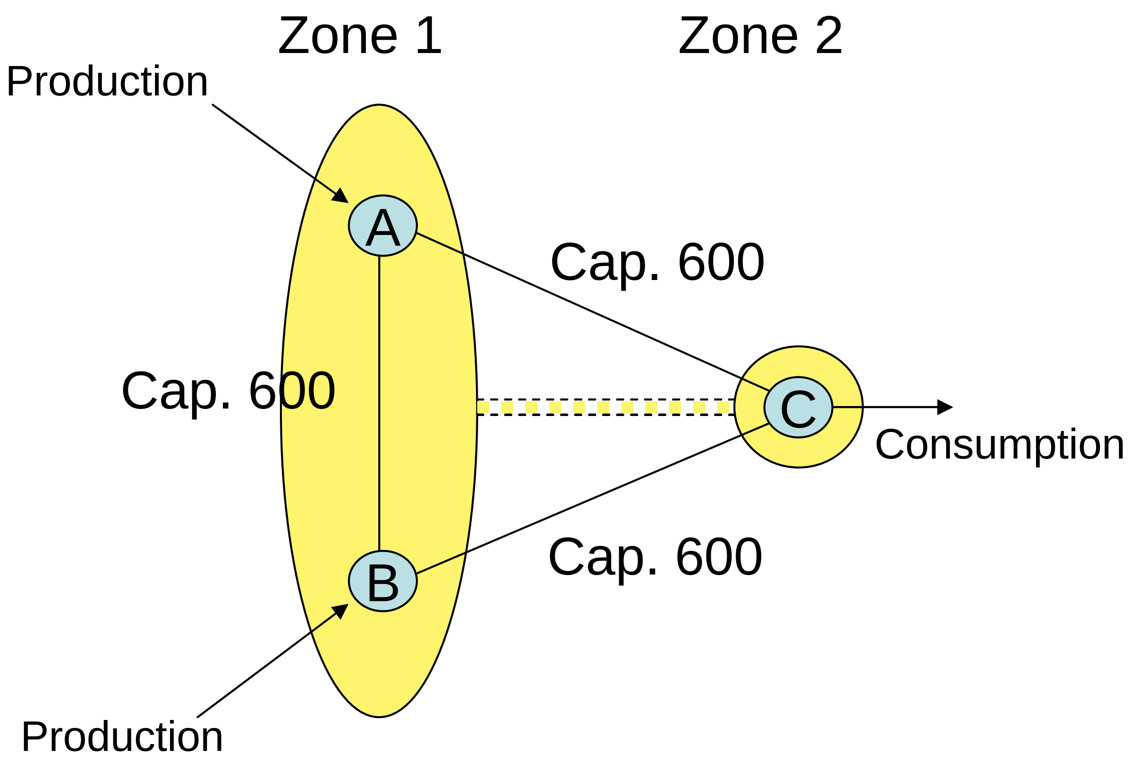
f_{BC} = 1/3 q_A + 2/3q_B

f_{AB} = 1/3 q_A – 1/3 q_B

Which capacity to choose for the aggregated link between zone 1 and zone 2?

	qa	qb		
	600	600		
	Injection in A	Injection in B	Flows	AC+BC
Link AC	0,67	0,33	600	1200
Link BC	0,33	0,67	600	
Link AB	0,33	-0,33	0	

Example



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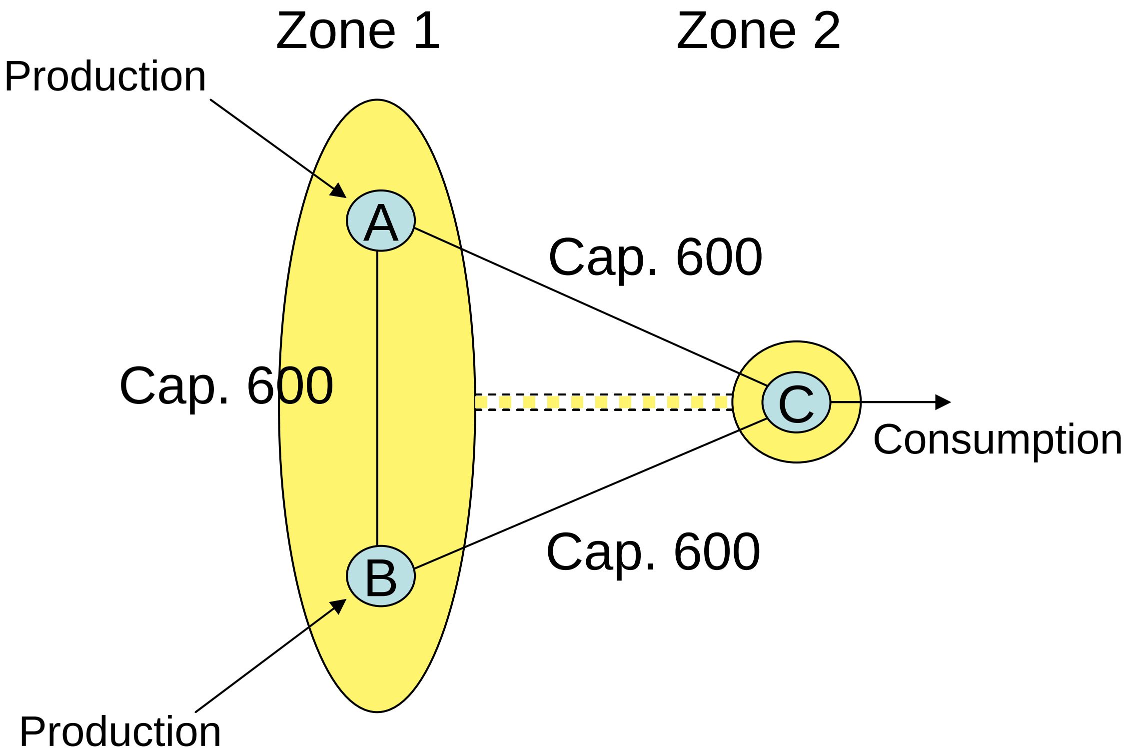
Which capacity to choose for the aggregated link between zone 1 and zone 2?

	qa	qb		
	1200	0		
	Injection in A	Injection in B	Flows	AC+BC
Link AC	0,67	0,33	800	1200
Link BC	0,33	0,67	400	
Link AB	0,33	-0,33	400	

Example



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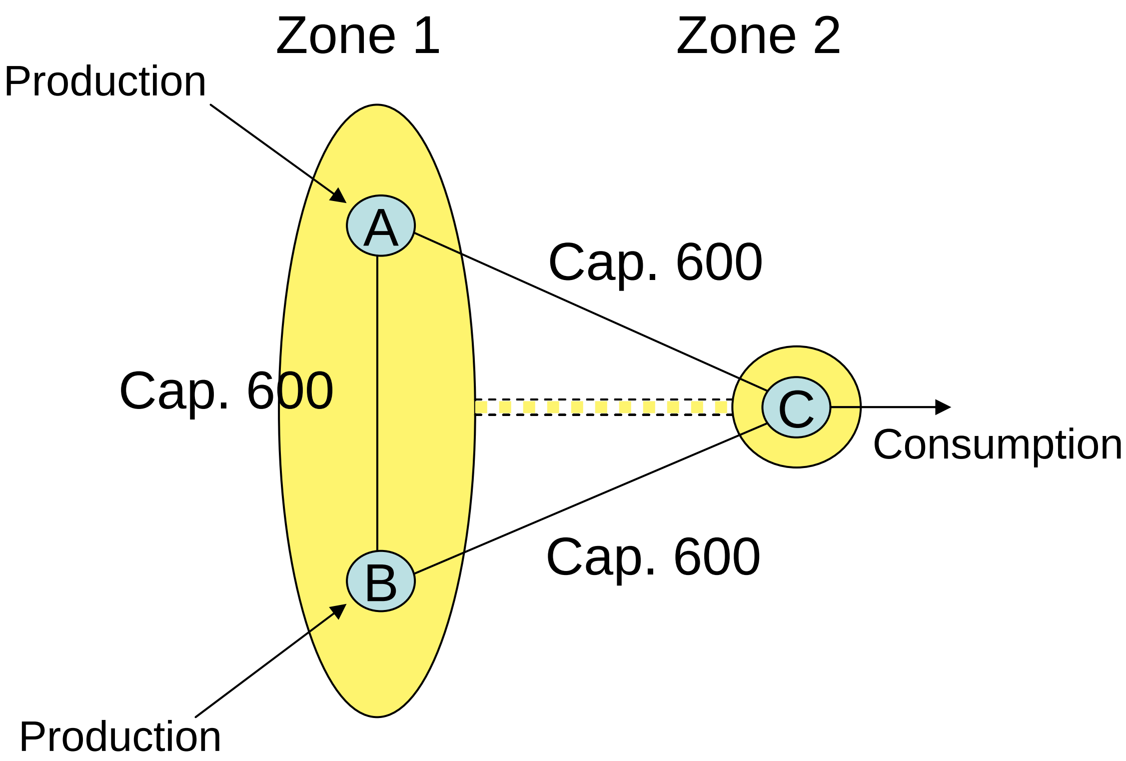
$f_{BC} = 1/3\ q_A + 2/3 q_B$

$f_{AB} = 1/3\ q_A - 1/3\ q_B$

Which capacity to choose for the aggregated link between zone 1 and zone 2?

	qa	qb		
	900	0		
	Injection in A	Injection in B	Flows	AC+BC
Link AC	0,67	0,33	600	900
Link BC	0,33	0,67	300	
Link AB	0,33	-0,33	300	

Example



$f_{AC} = 2/3\ q_A + 1/3\ q_B$

$f_{BC} = 1/3\ q_A + 2/3 q_B$

$f_{AB} = 1/3\ q_A - 1/3\ q_B$

Which capacity to choose for the aggregated link between zone 1 and zone 2?

	qa	qb		
	850	100		
	Injection in A	Injection in B	Flows	AC+BC
Link AC	0,67	0,33	600	950
Link BC	0,33	0,67	350	
Link AB	0,33	-0,33	250	

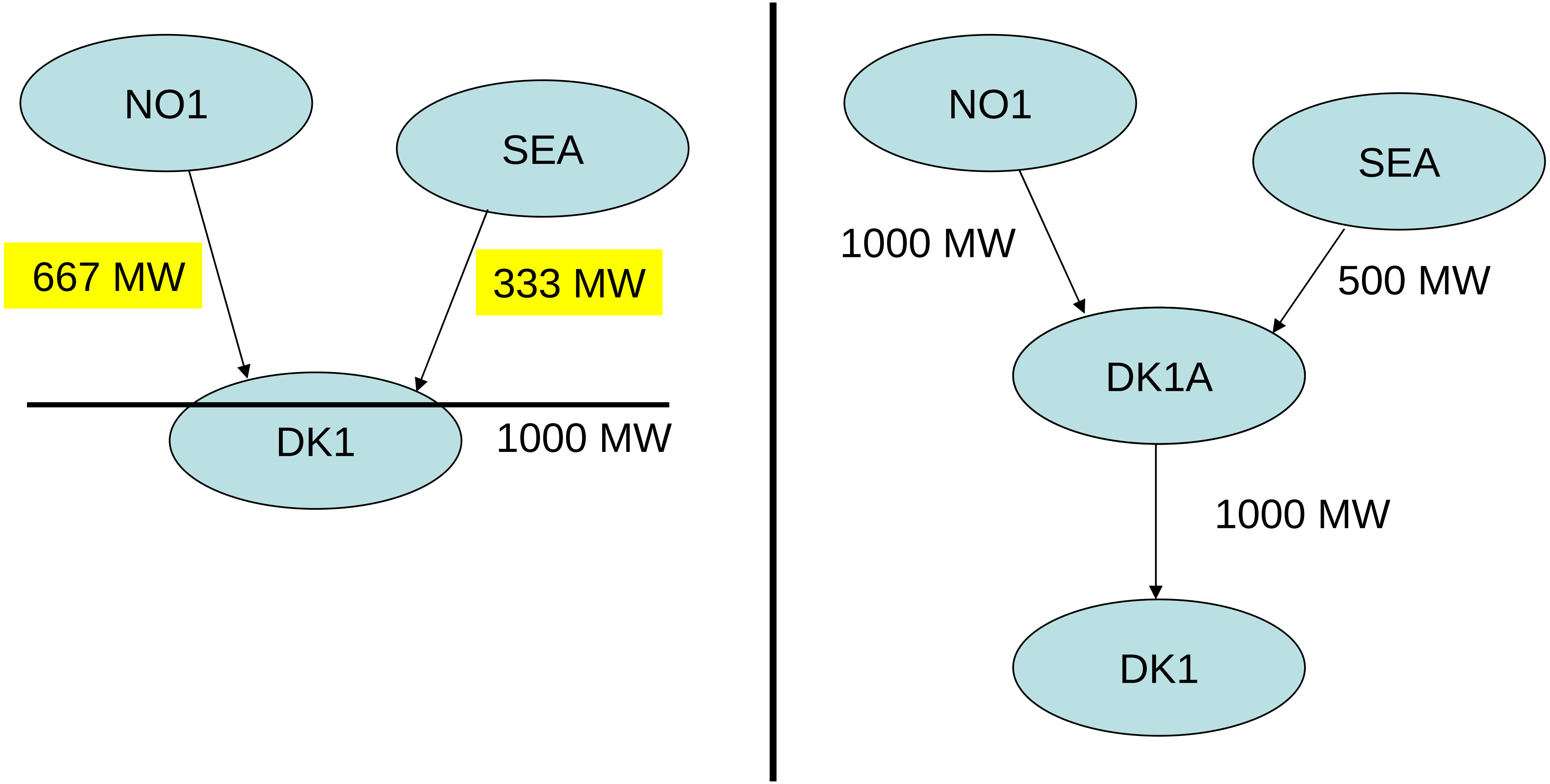
Conclusions

- Show potential for improving the methods for congestion management in the Nord Pool area
- Possible to move in direction of optimal zonal prices
  - More zones / improved power flow model
  - Prices based on better information of bids and capacities
  - More market based management of internal and external bottlenecks
  - Possible to implement without major changes in pricing algorithm (SESAM)

Main Message

- Aggregation
  - Economic
  - Physical
- Need not to be identical
  - Bids can be nodal based
  - Capacities can be set on ”individual lines”
  - Prices can be computed on zonal level
    - Takes internal constraints directly into account
    - Are based on the real limitations of the system

Optimization Routine to Determine Capacity Utilization



Volumes

- 70-80 % of physical power is traded at Nord Pool