

Nordic Flow-Based Market Coupling

- Priyanka Shinde
Nordic Market Expert at Montel Analytics

1. Market timeline and competition

2. Introduction to Market Coupling

3. Connection to the physical grid

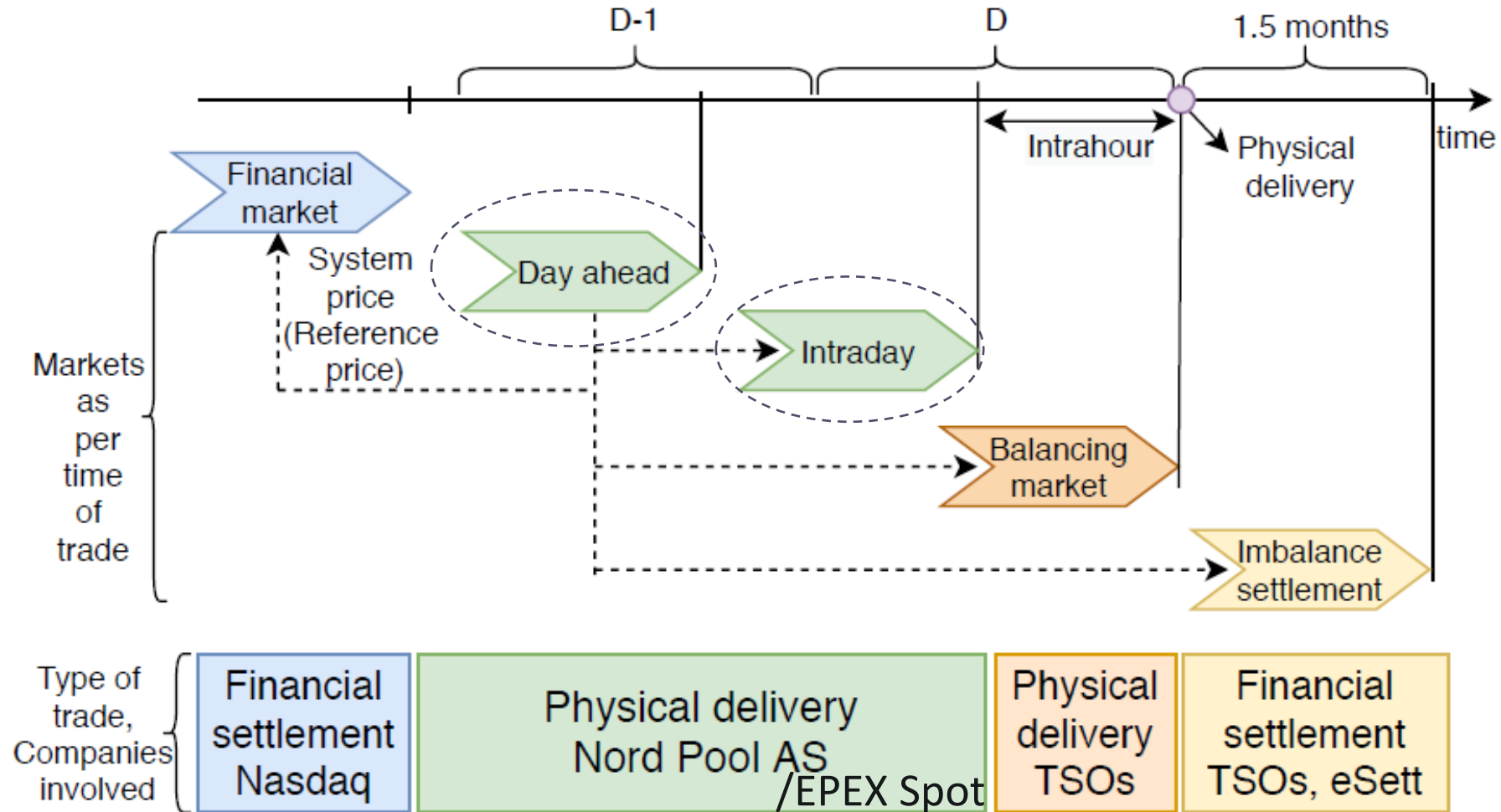
4. Results from Nordic
flow-based parallel runs

5. Topics for further discussions

6. Conclusion

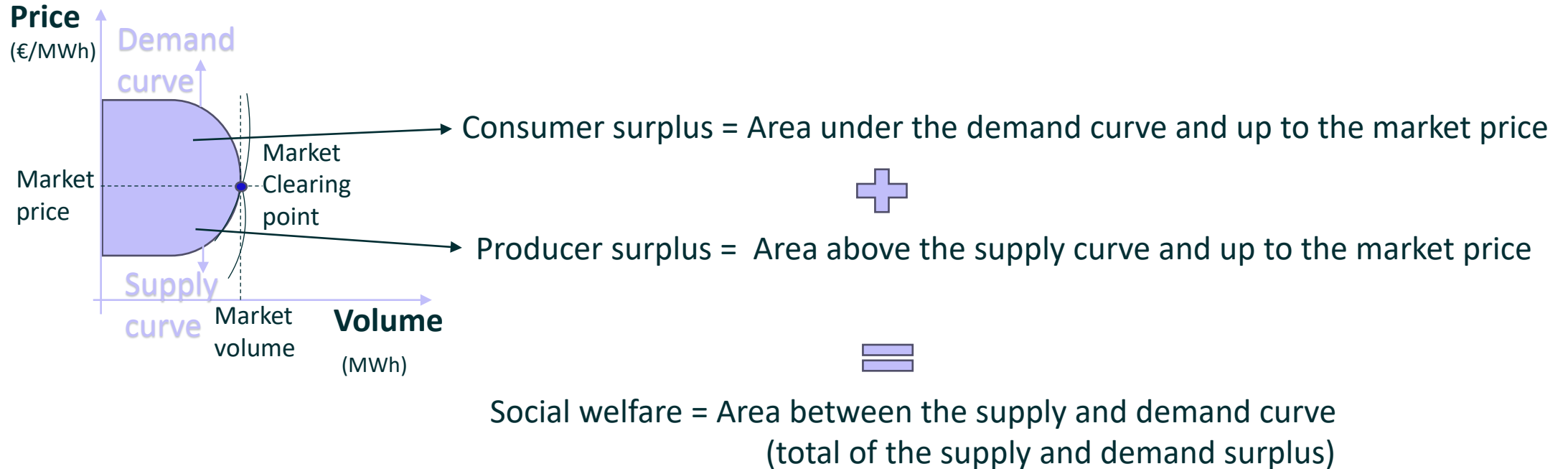
1. Market timeline and competition

Market Timeline



Competition in market

- To drive innovation, improve transparency



Market clearing point is determined by:

Maximize Social welfare
Subject to:
Supply - demand balance (price = Lagrangian multiplier)
Supply side constraints
Demand side constraints

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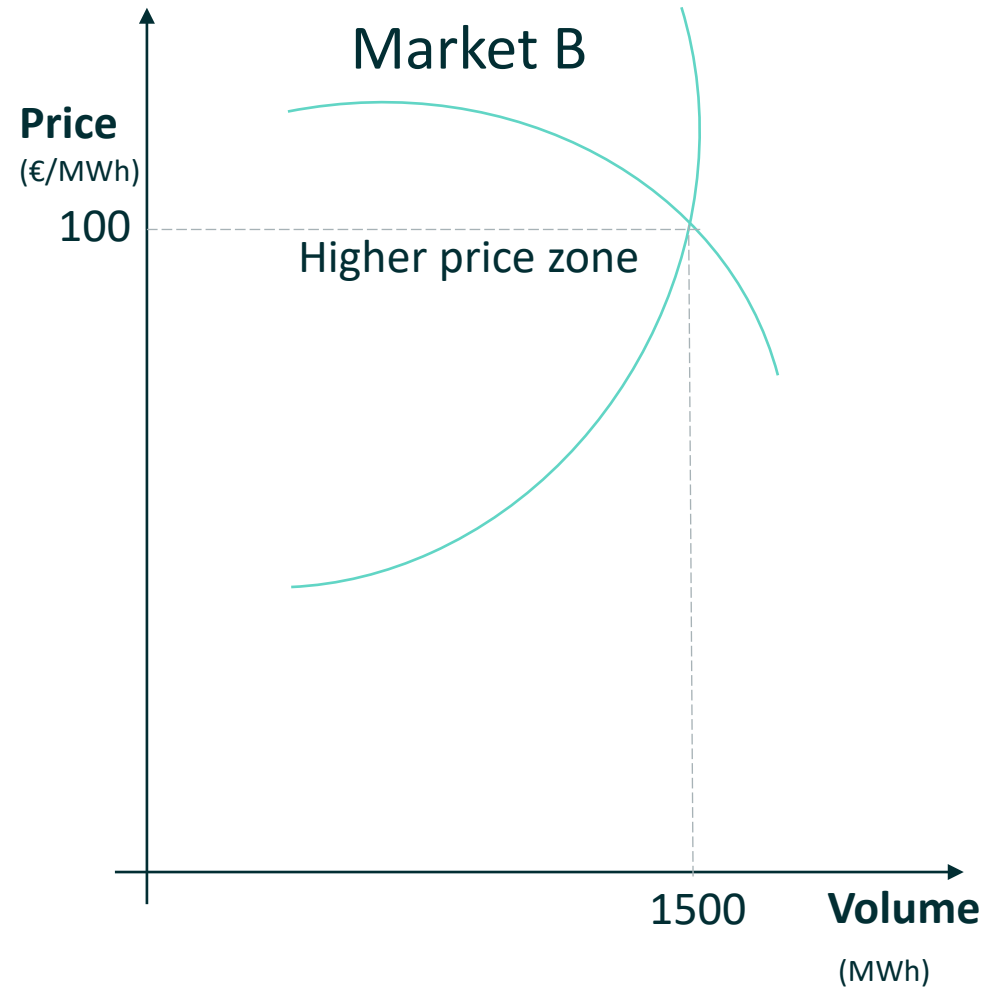
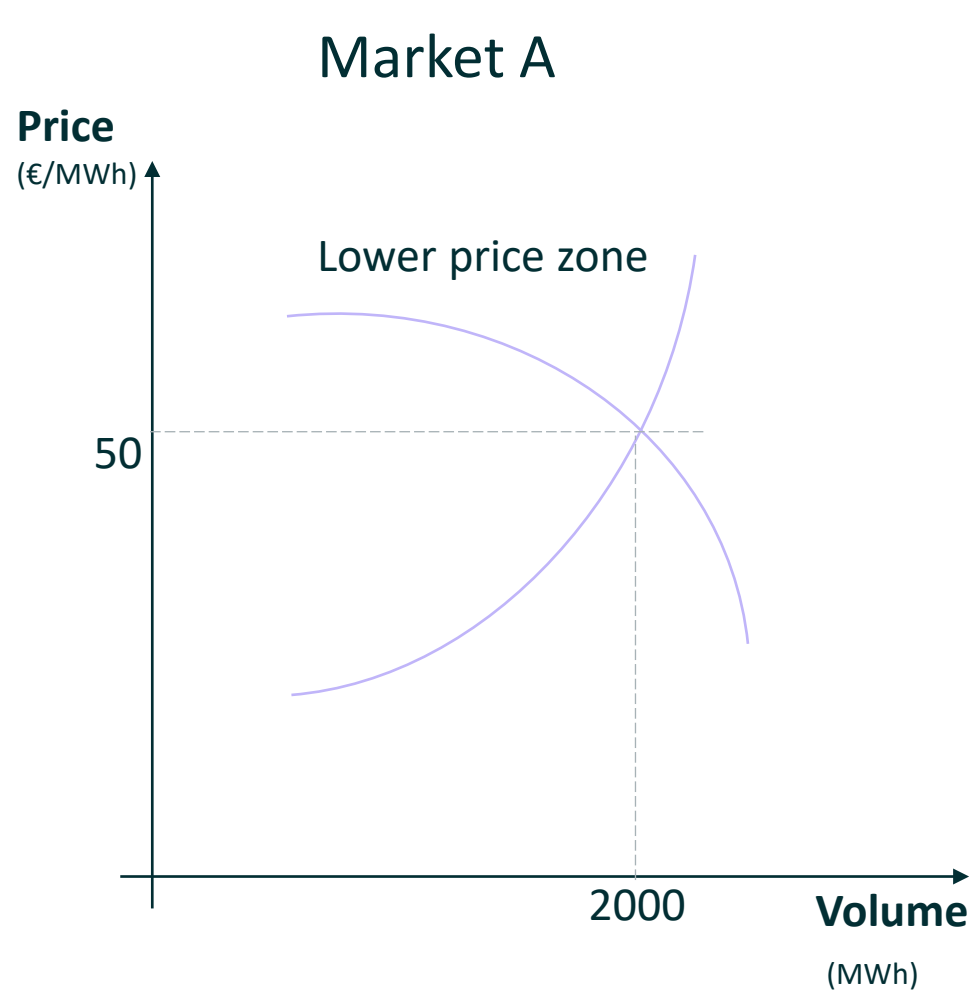
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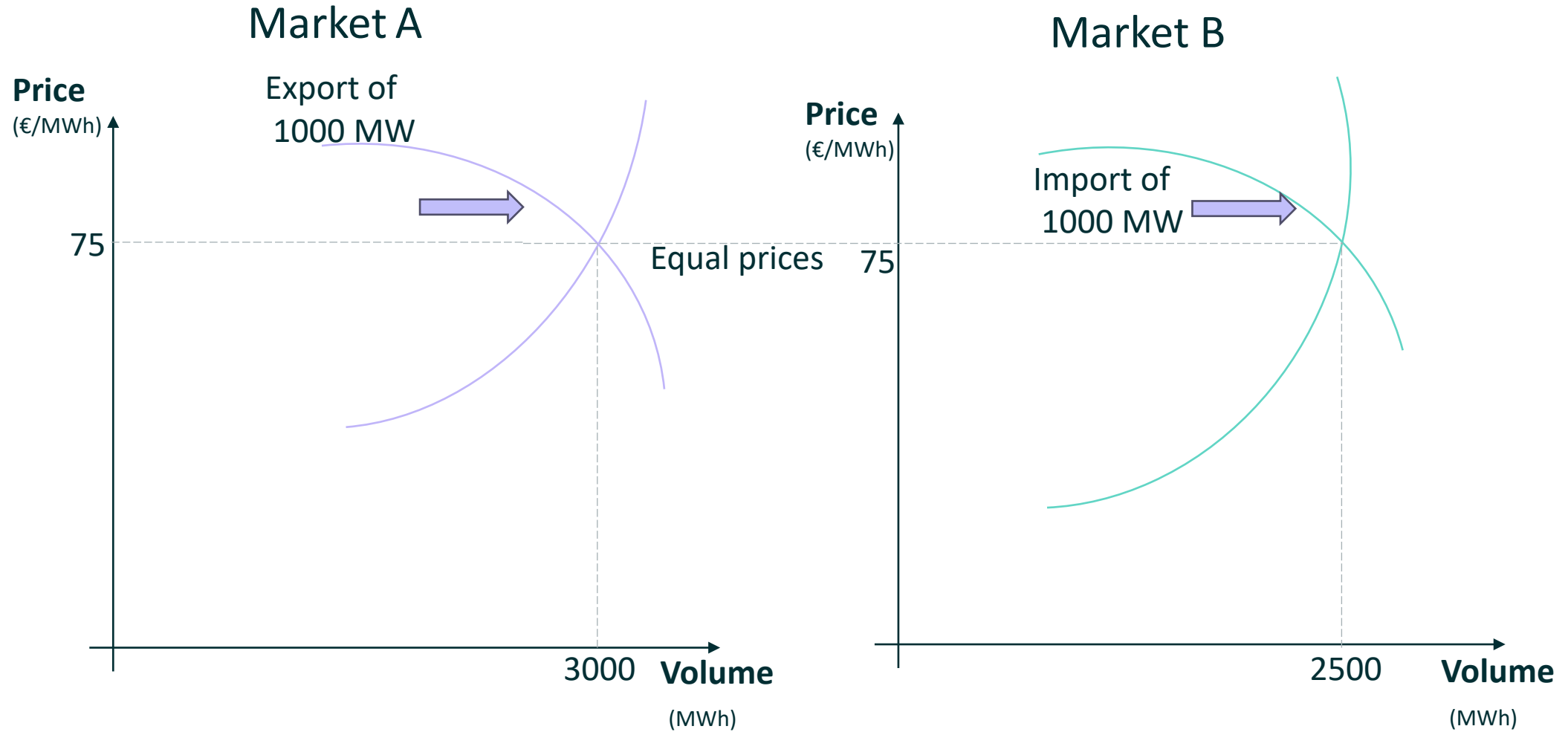
2. Introduction to Market Coupling

Case 1: Uncoupled Markets



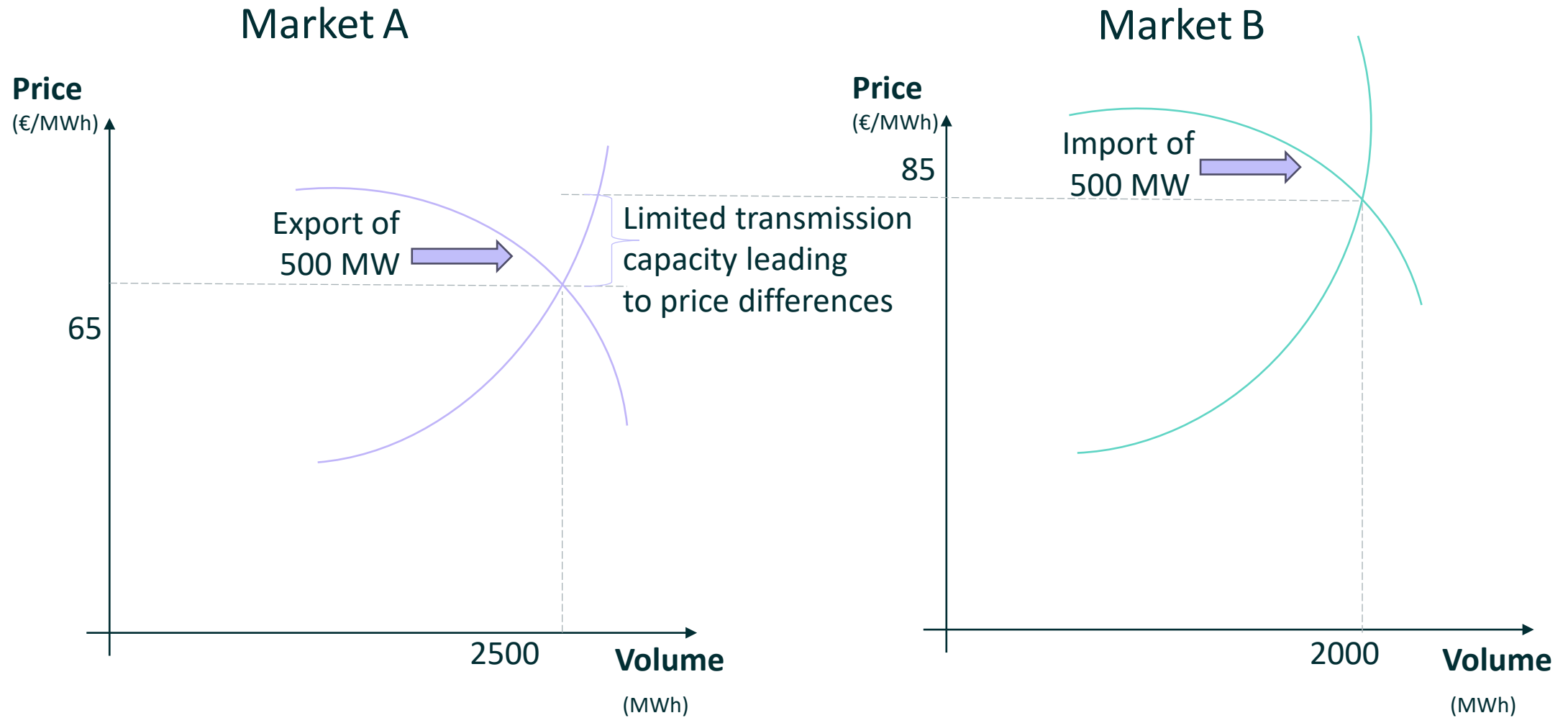
- Bidding zones A and B operate as separate markets and have their own prices due to no exchange in between them.

Case 2: Fully Coupled Markets



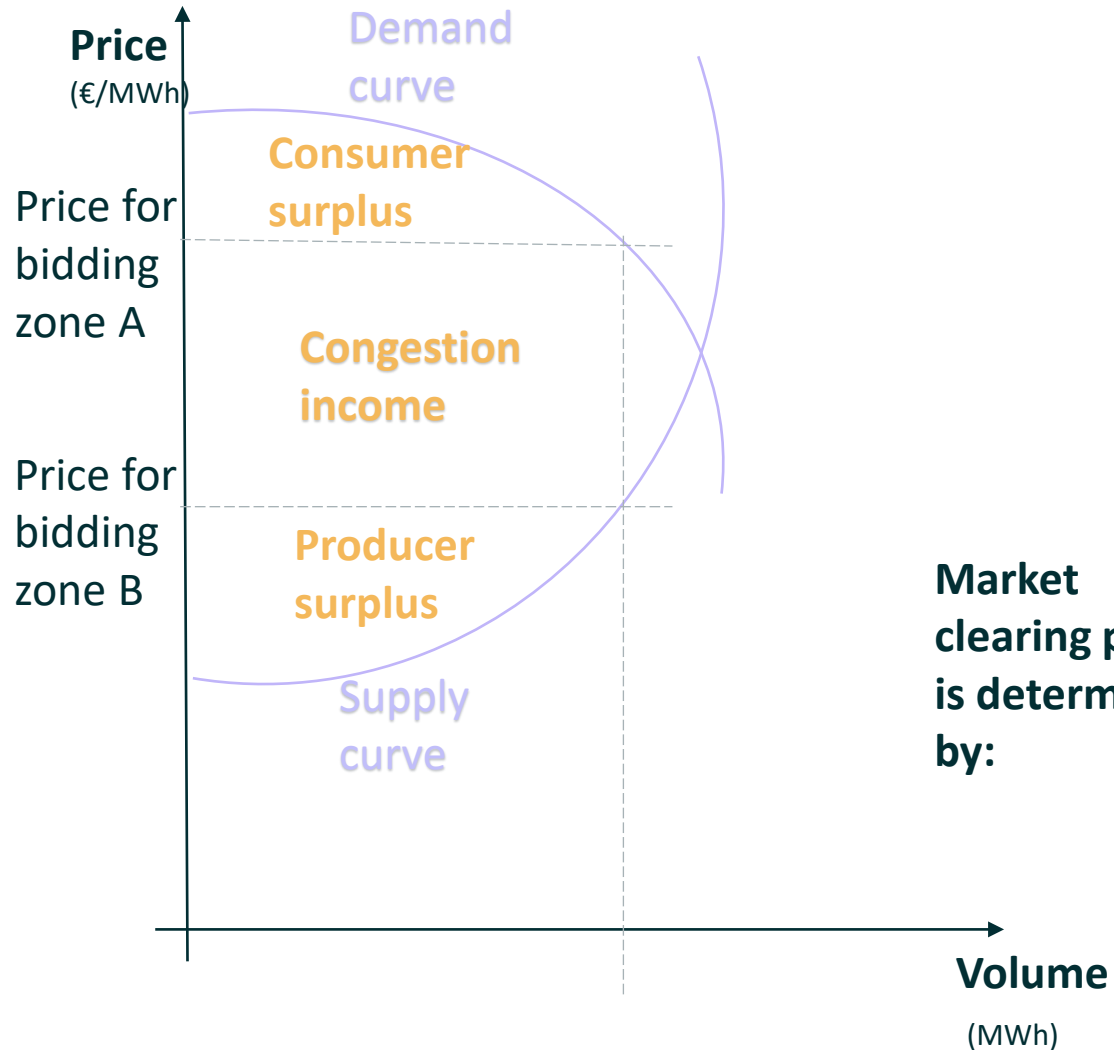
- Bidding zones A and B have enough transmission capacity to allow for exchanges such that prices are equal in both zones.
- Intuitive flows: flow from low price zone to higher price zone (improves social welfare)

Case 3: Partially Coupled Markets



- Price differences arises due to congestion in the network.
- This price difference multiplied by the exchanged volume gives the congestion income to TSOs.

Market clearing with transmission constraints



Market clearing point is determined by:

Social welfare = Producer surplus +
Congestion income +
Consumer surplus

Maximize Social welfare
Subject to:
Supply - demand balance (price = Lagrangian multiplier)
Transmission constraints
Supply side constraints
Demand side constraints

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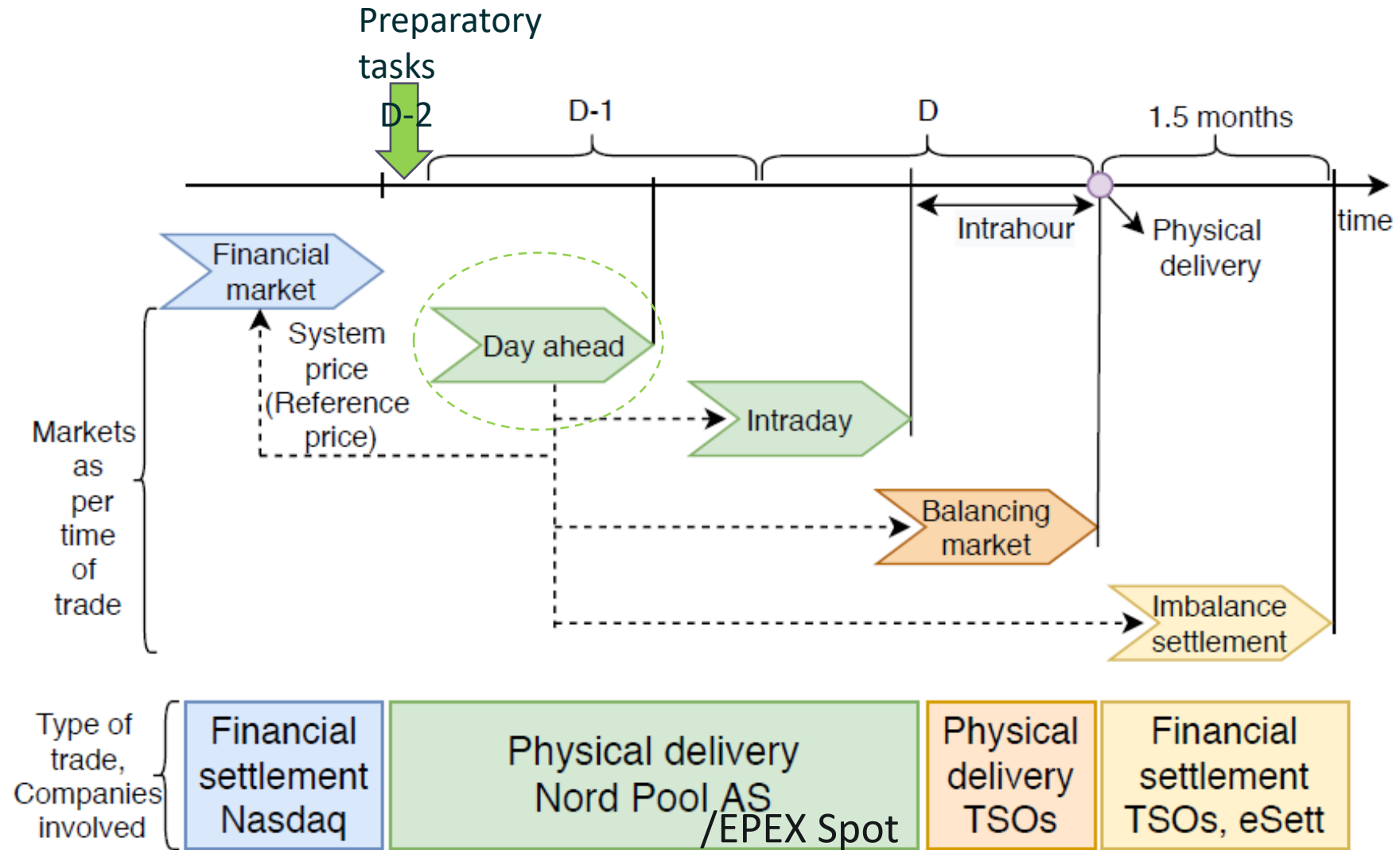
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Back to the timeline

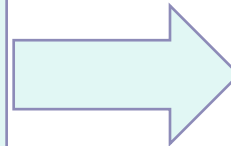


Relation of electricity market to physical grid

Physical grid



Detailed grid model



Bidding zone model

Capacity calculation is done by translating the complex physical grid into a simplified form that can be utilised by the power exchange

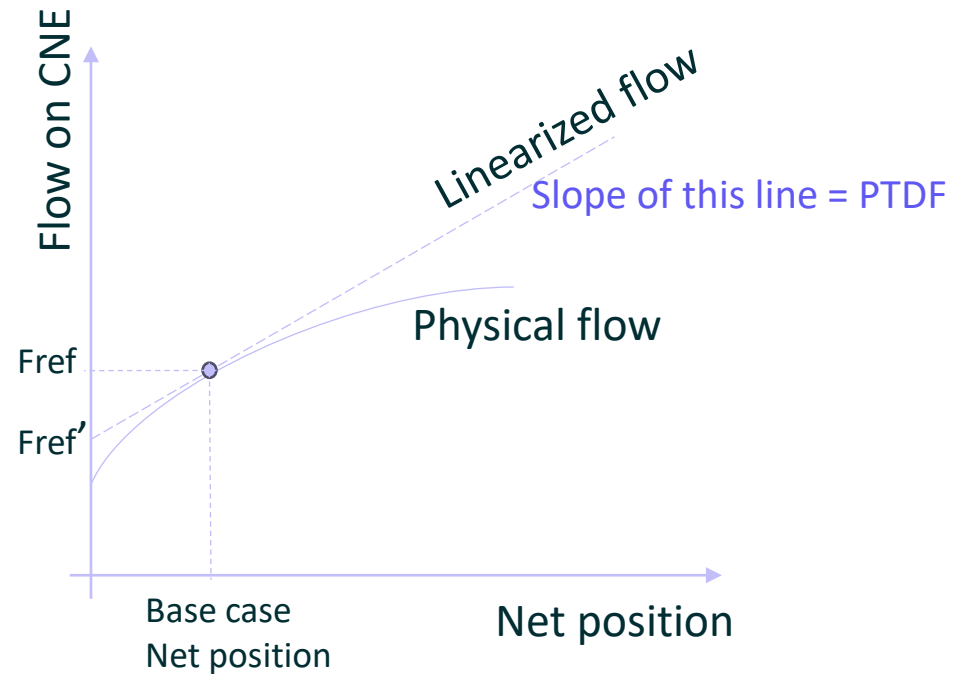
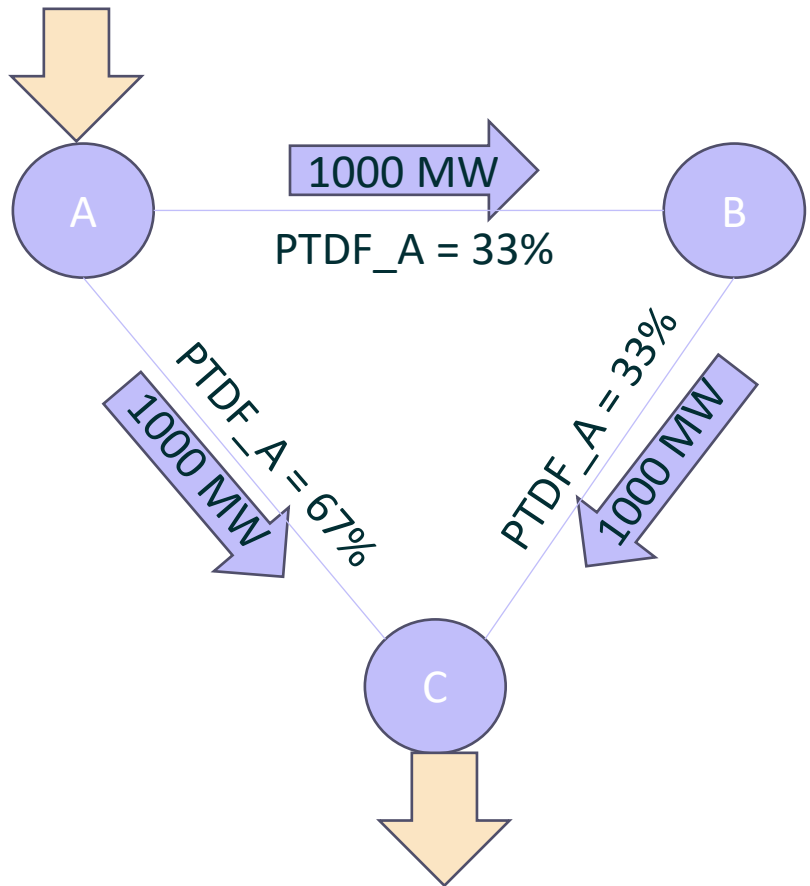
Commercial representation



- **Zonal pricing:** In a zonal market, the transmission system is divided into several zones and the wholesale price of electricity is set for each settlement period, as a separate uniform price for each zone.
- **Nodal pricing:** The price at each node reflects the locational value of energy (incremental cost of serving one additional MW of load at each location subject to system constraints), including the cost of the energy and the full cost of delivering it including network losses and congestion.

Nodal representation and PTDFs

Nodal market model

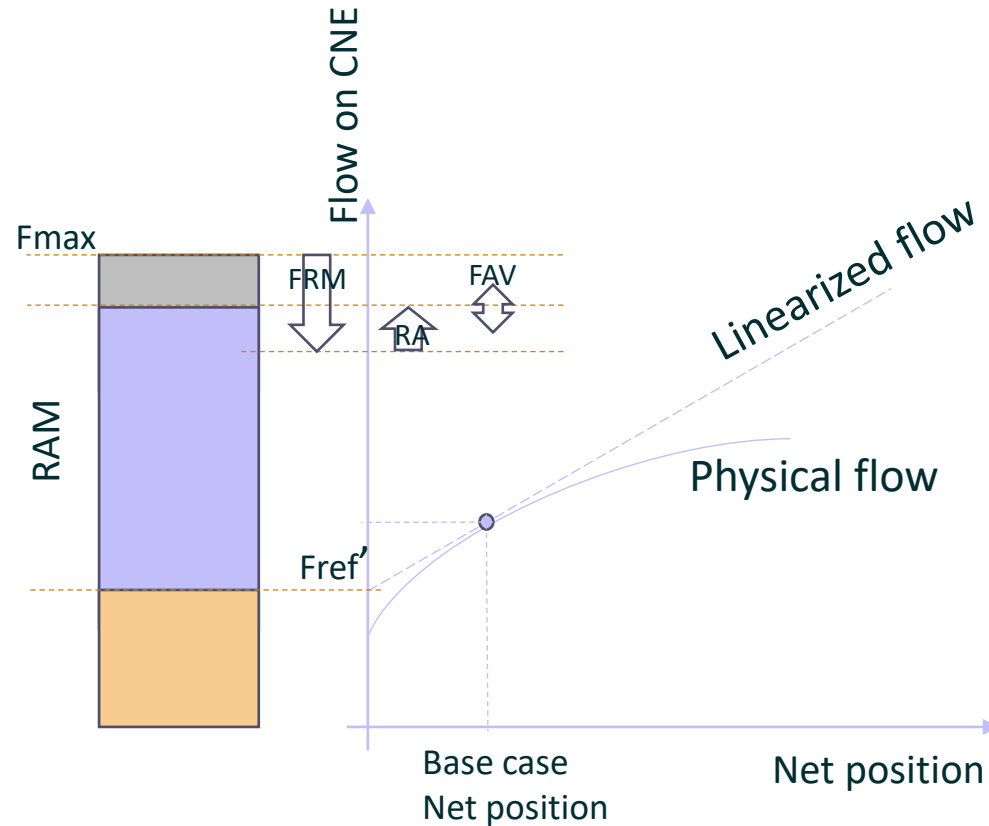


$$F_{ref} = F_{ref}' + PTDF * NP$$

- Physical flows are non-linear function of net positions.
- To find PTDF: DC load flow analysis
- Linearization at Base case net position

PTDF: Power Transfer Distribution Factor

Deriving Remaining Available Margins (RAM)

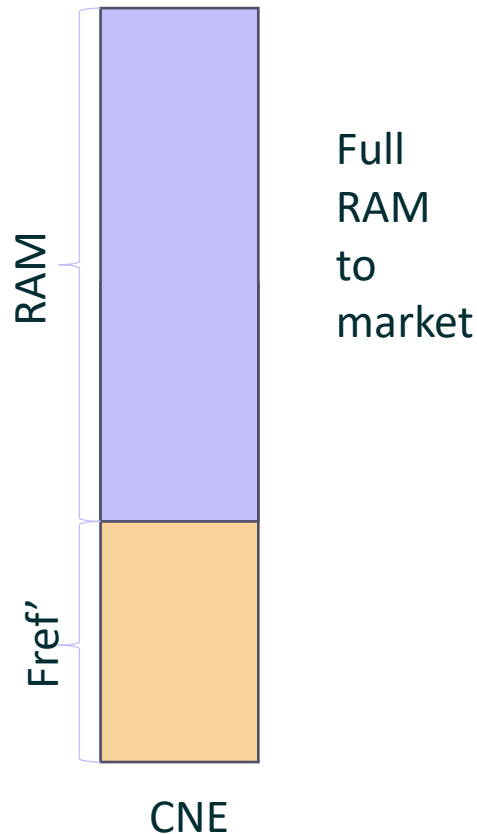


- F_{max} : the maximum allowed flow on a CNE/operational security limit
- This maximum flow is then altered due to:
 - Flow Reliability Margin (FRM)
 - Remedial Action (RA)
 - Final Adjustment Value (FAV)
- The net capacity available after the alterations: $F_{max} - FRM + RA - FAV$
- The flow on CNE can be given as: $F_{ref}' + PTDF * NP$
- Market constraint:
 - $F_{ref}' + PTDF * NP \leq F_{max} - FRM + RA - FAV$
 - $PTDF * NP \leq RAM$

where $RAM = F_{max} - FRM + RA - FAV$

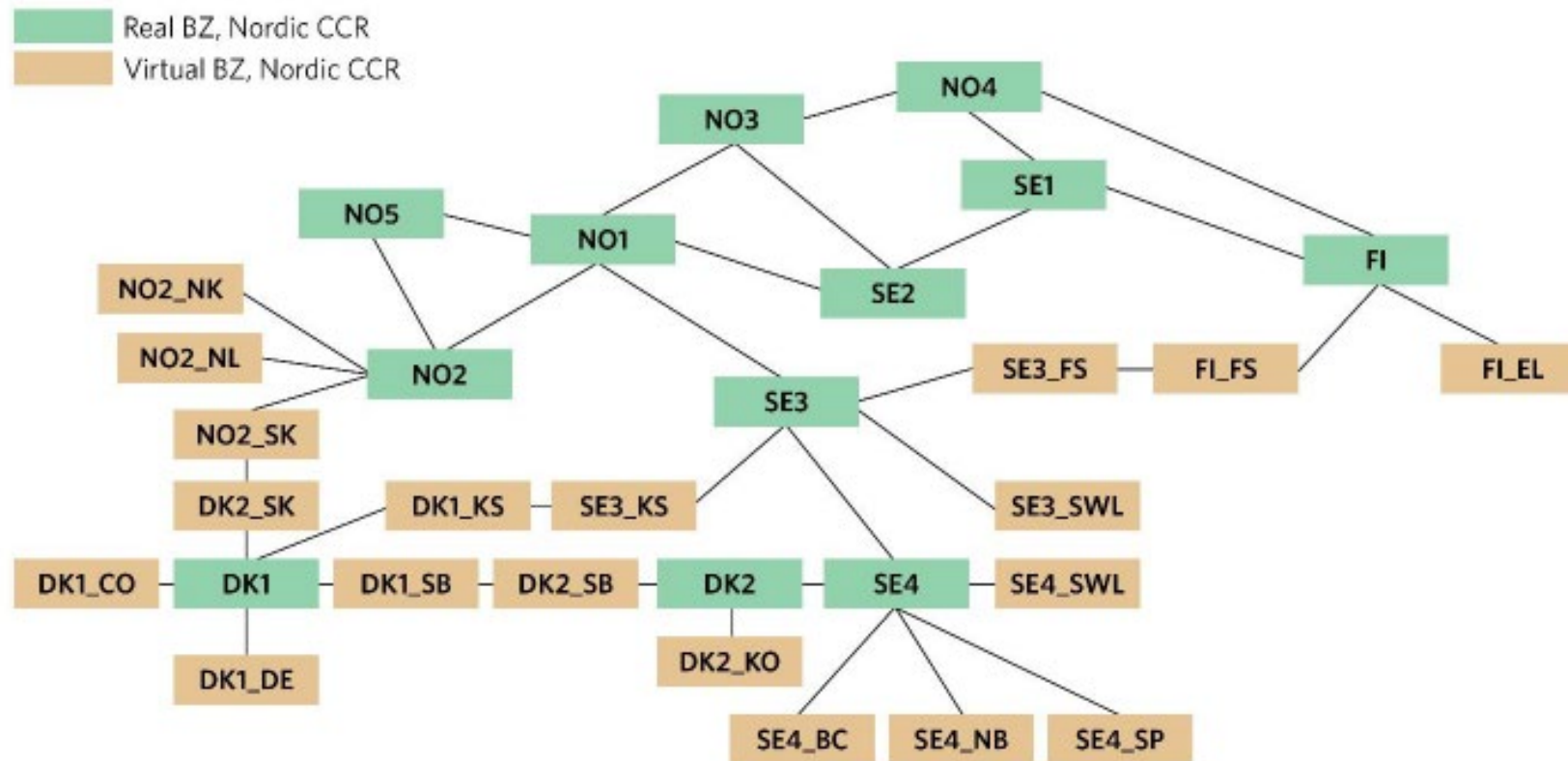
HVDC lines as virtual bidding zones

Advanced hybrid coupling



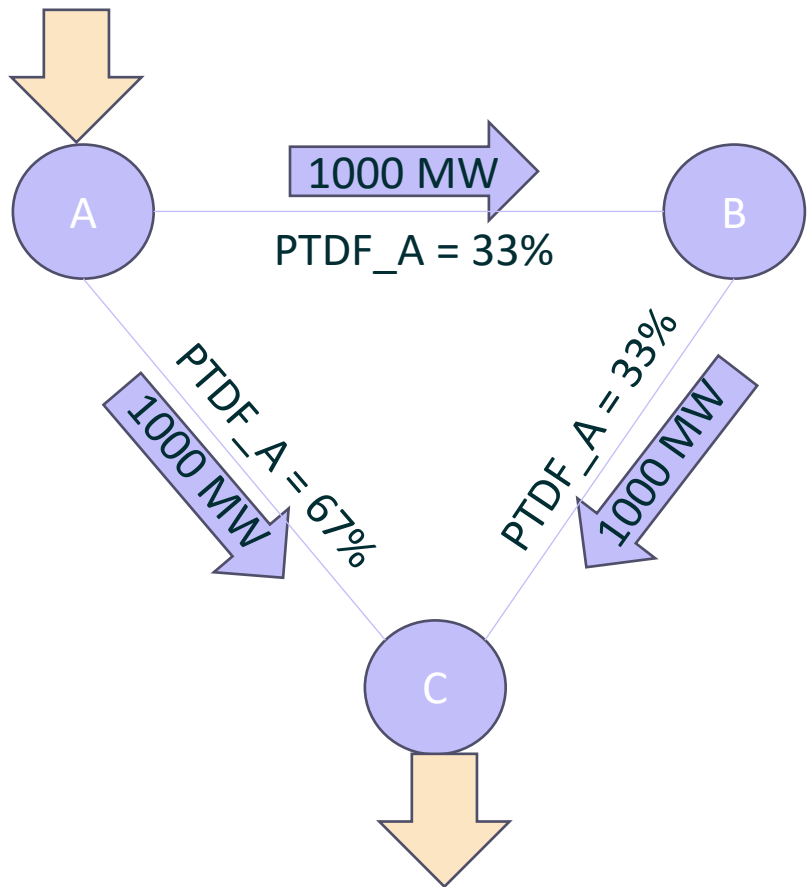
- Flow on HVDC lines and radial AC lines are controllable by operators (unlike AC lines in a meshed network).
- For HVDC lines, market can schedule a flow and operator can realize it.
- Advanced hybrid coupling is a method popularly used for managing HVDC and AC lines in the same network.
- PTDFs of the transformer station at HVDC lines used for calculating flows due to HVDC lines on AC lines.

Nordic Capacity Calculation Region (CCR) topology



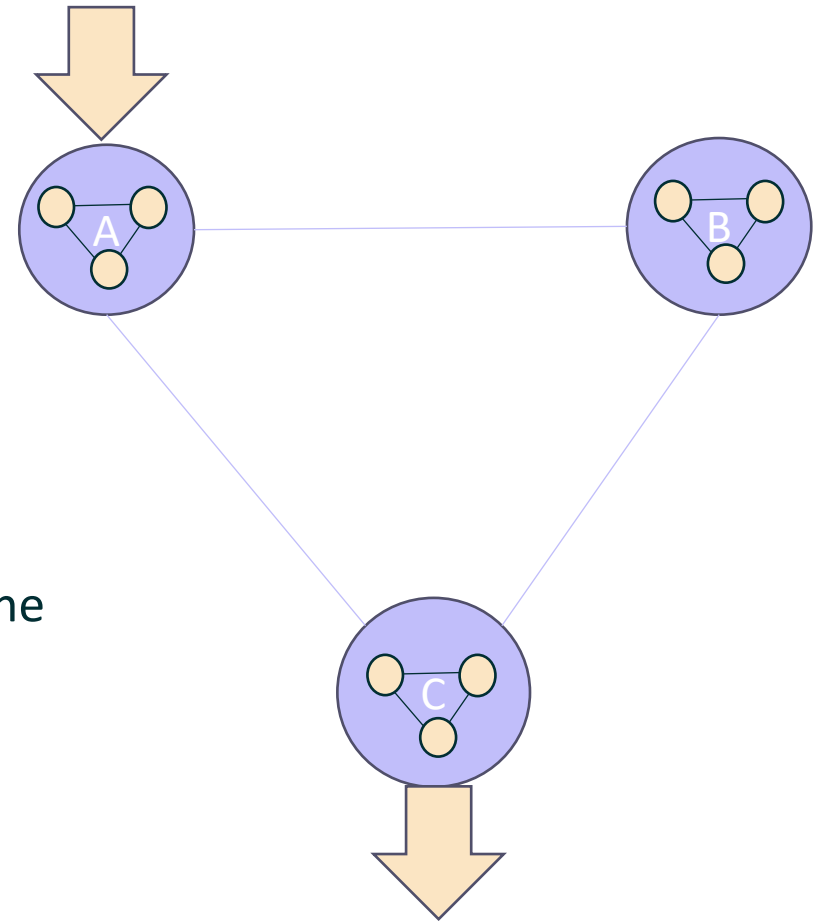
- 12 real bidding zones in the Nordics
- HVDC links are also modelled as bidding zones in the flow-based methodology
- 19 HVDC links lead to 19 virtual bidding zones
- Total bidding zones: 31

Nodal to zonal representation

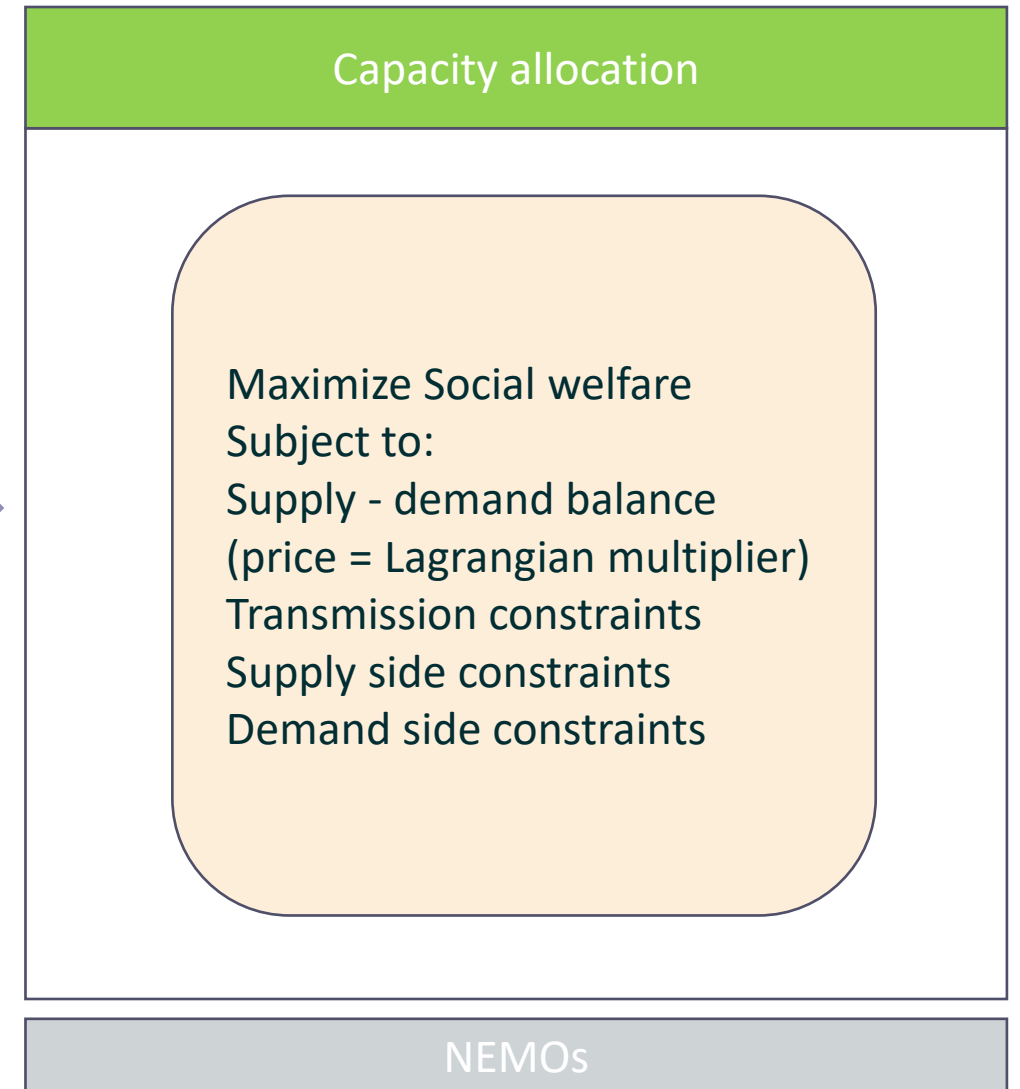
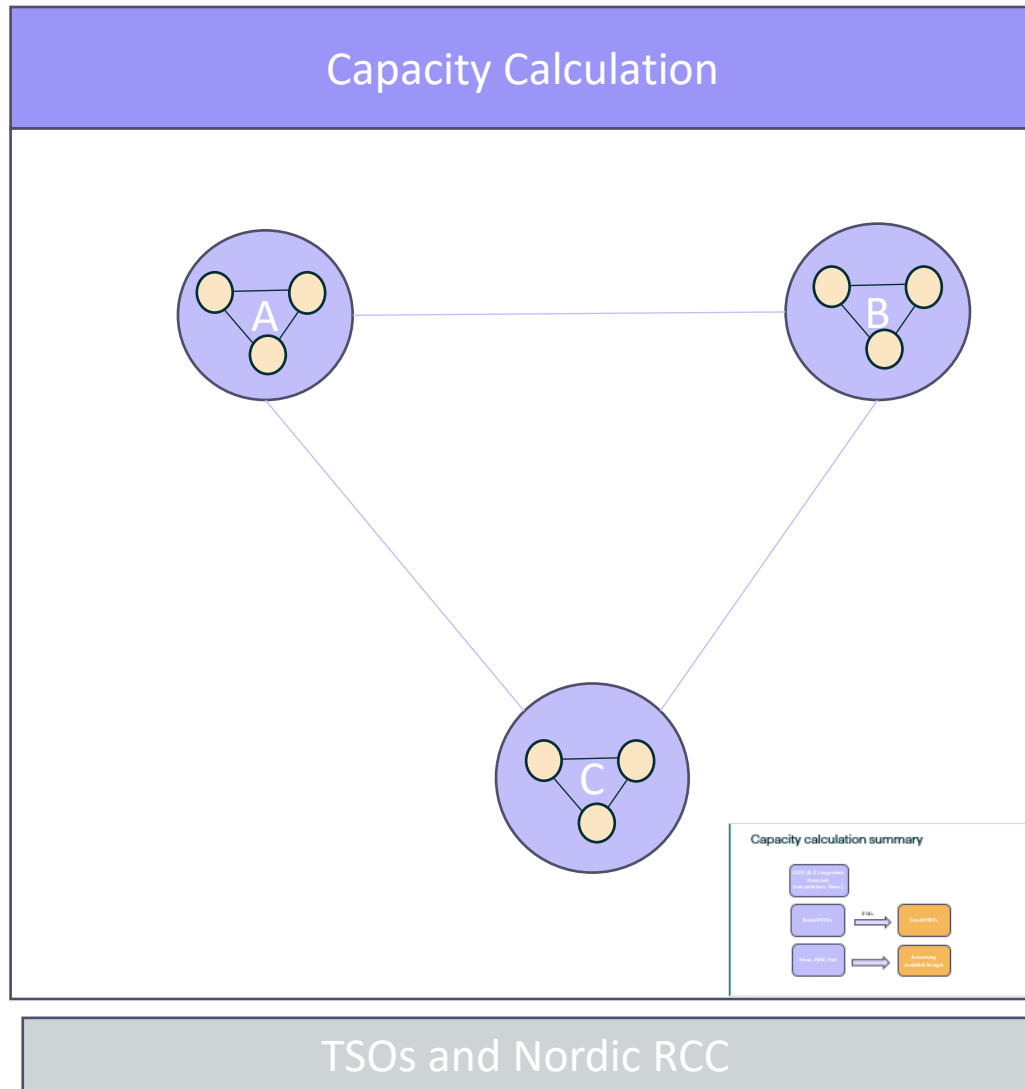


Node to bidding zone
(GSK: Generation
Shift Key factor)

Zonal market model

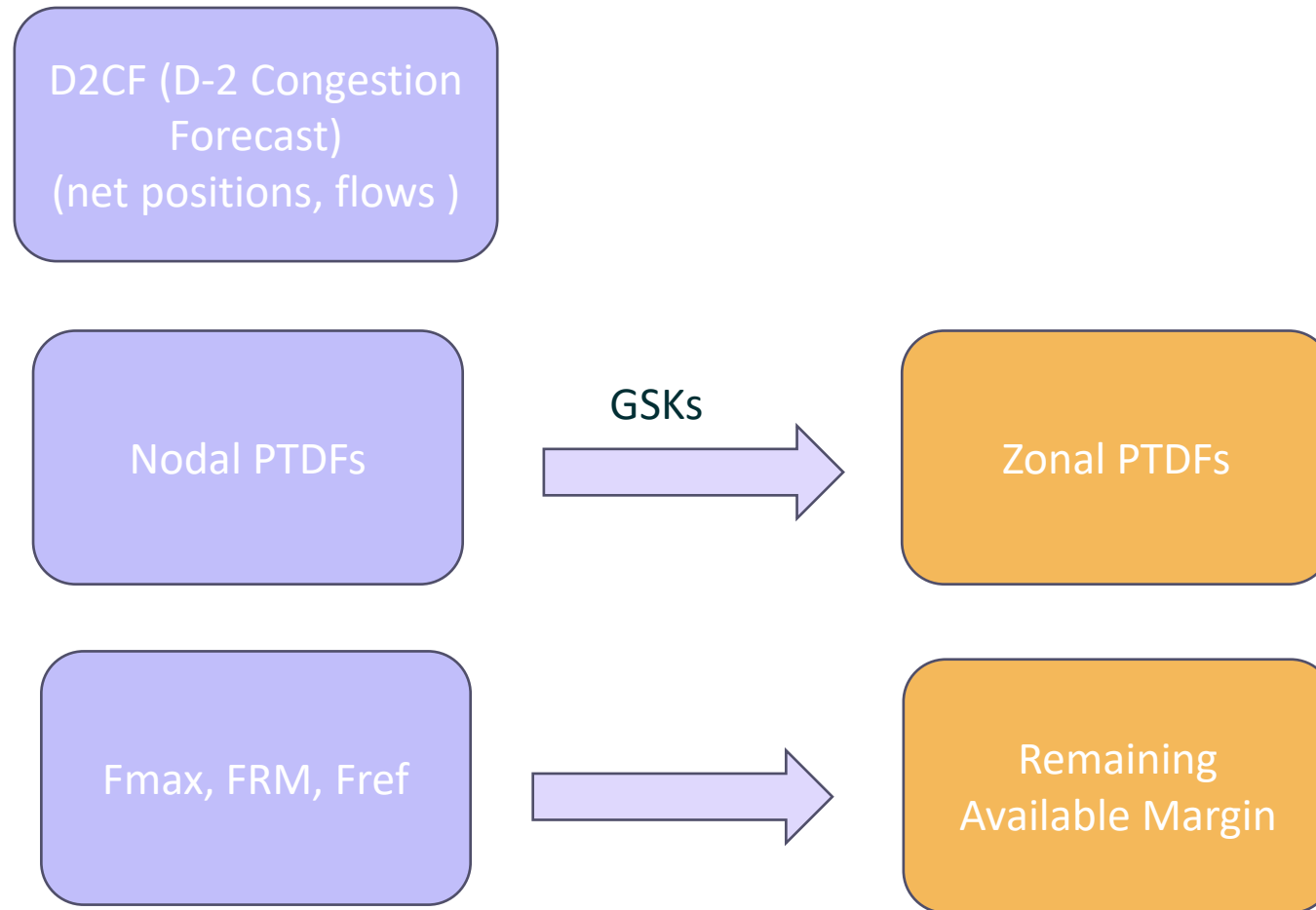


Process of market coupling

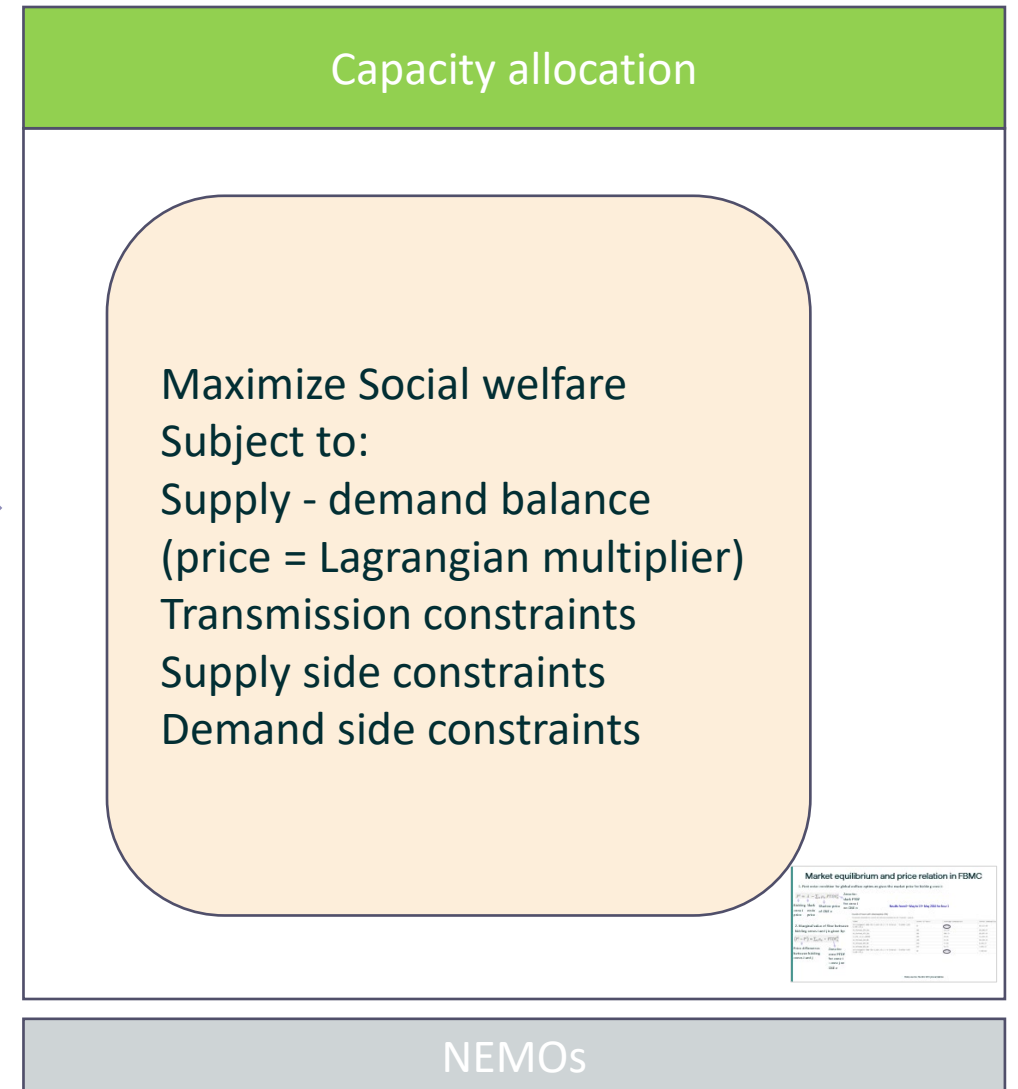
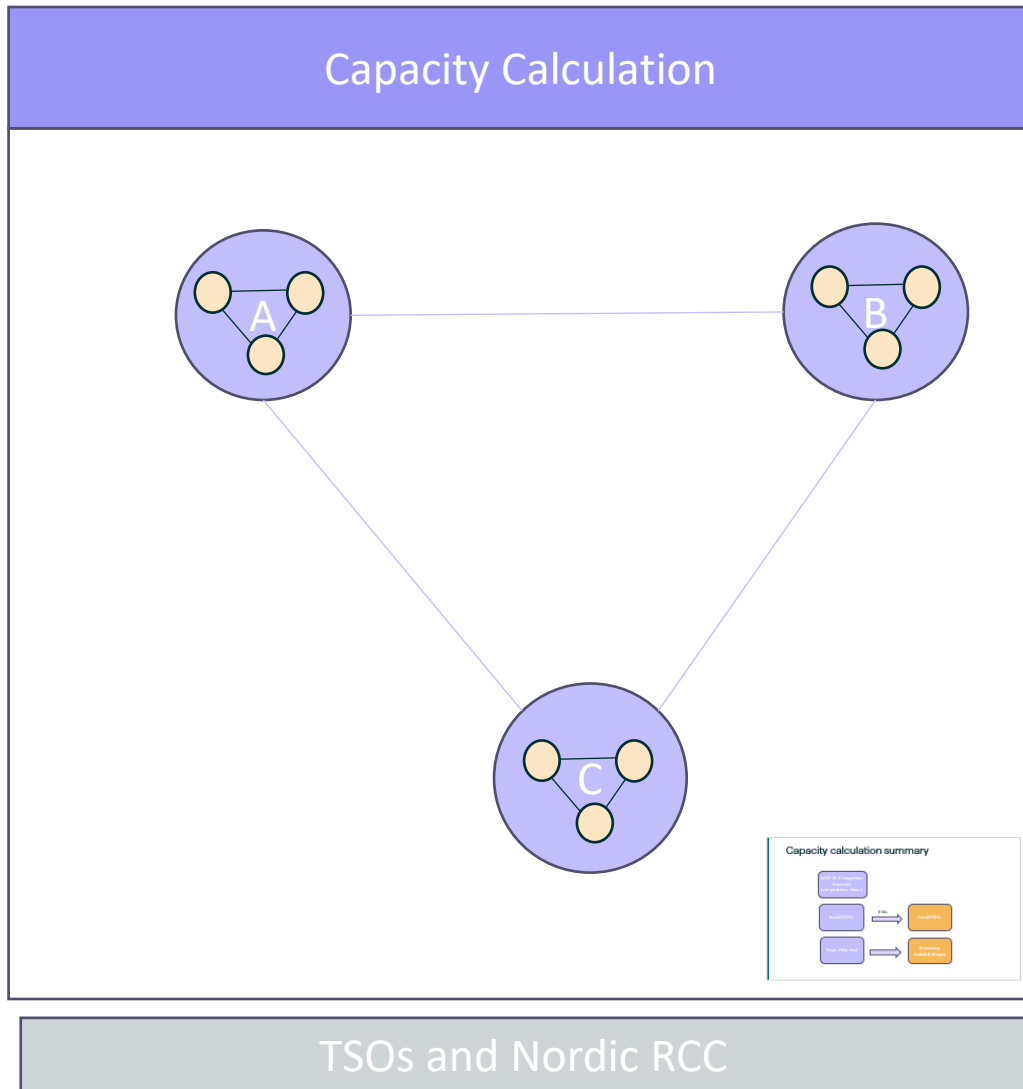


time

Capacity calculation summary



Process of market coupling



time

Market equilibrium and price relation in FBMC

1. First order condition for global welfare optimum gives the market price for bidding zone i:

$$P^i = \lambda - \sum_n \rho_n PTDF_n^i$$

↓ Bidding zone i price
↓ Slack node price
↓ Shadow price of CNE n
↓ Zone-to-slack PTFDF for zone i on CNE n

Results from 6th May to 19th May 2024 for hour 1

2. Marginal value of flow between bidding zones i and j is given by:

$$(P^j - P^i) = \sum_n \rho_n * PTDF_n^{ij}$$

↓ Price differences between bidding zones i and j
↓ Zone-to-zone PTFDF for zone i - zone j on CNE n

Counts of hours with shadowprice (FB)

Thousands separated by comma and decimal separated by dot. Example: 1,234.56

↻CNEC	↻Count of hours	↻Average shadowprice	↻Total shadowprice
ACLineSegment ENDK DK1 E_KAE-LYK_3 1 N Terminal : N 165KV LINE E_KAE-LYK_2	33	793.08	26,171.58
AC_Minimum_SE4_SWL	184	113.92	20,960.67
AC_Minimum_SE3_SWL	101	206.73	20,879.59
FI_PTC_FI_EL_EXPORT	203	56.61	11,492.19
AC_Minimum_SE4_NB	198	51.66	10,229.19
AC_Minimum_NO2_ND	226	37.02	8,366.27
AC_Minimum_NO2_NK	235	32.73	7,692.57
ACLineSegment ENDK DK1 E_KAE-LYK_3 1 N Terminal : N 165KV LINE E_KAE-LYK_1	10	736.98	7,369.83

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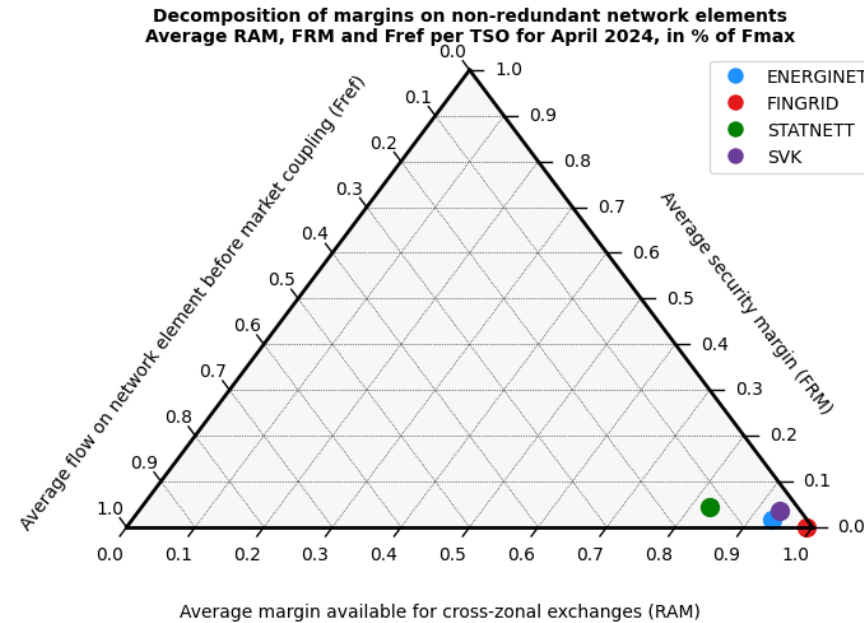
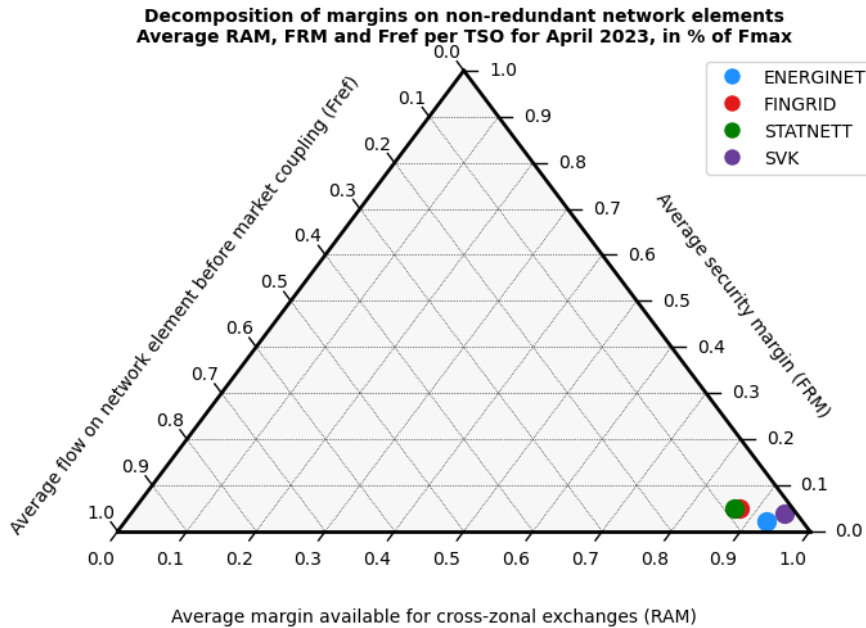
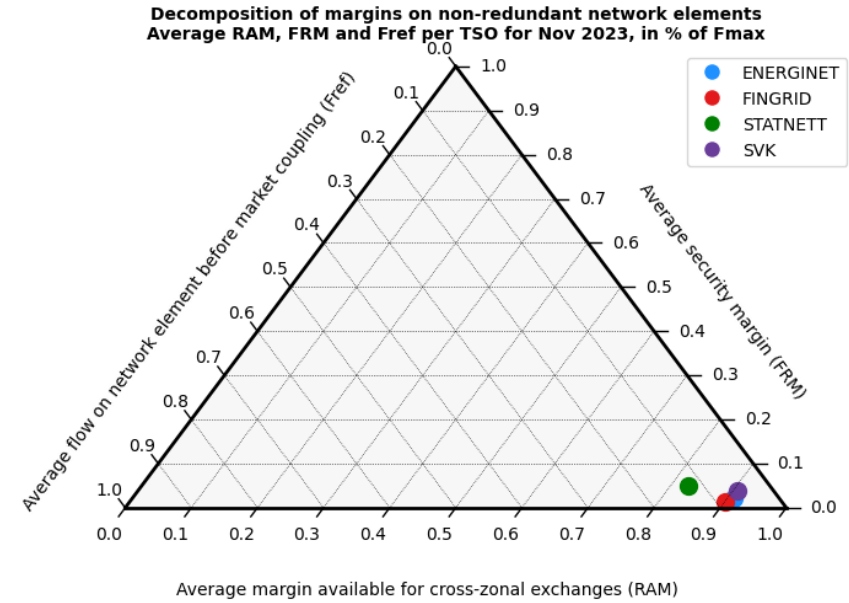
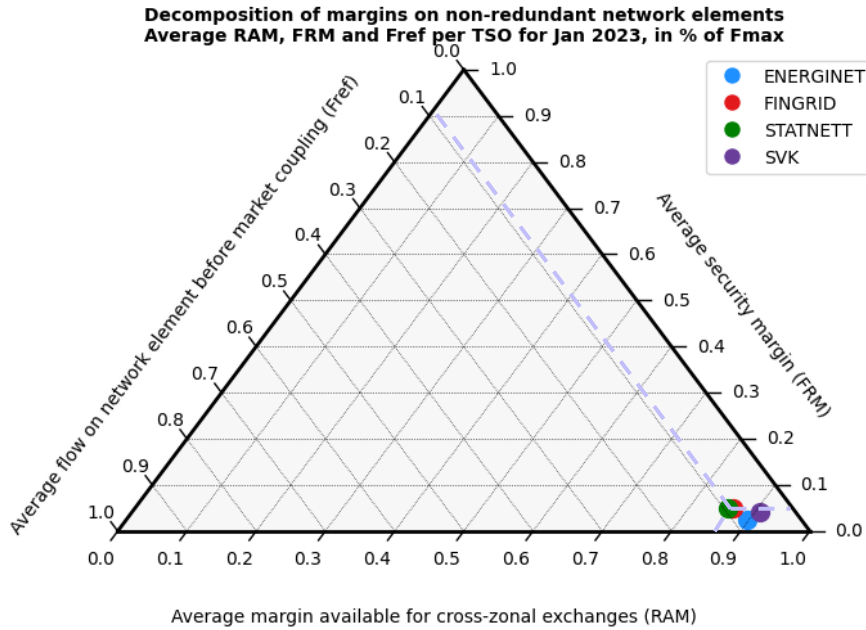
4. Results from Nordic
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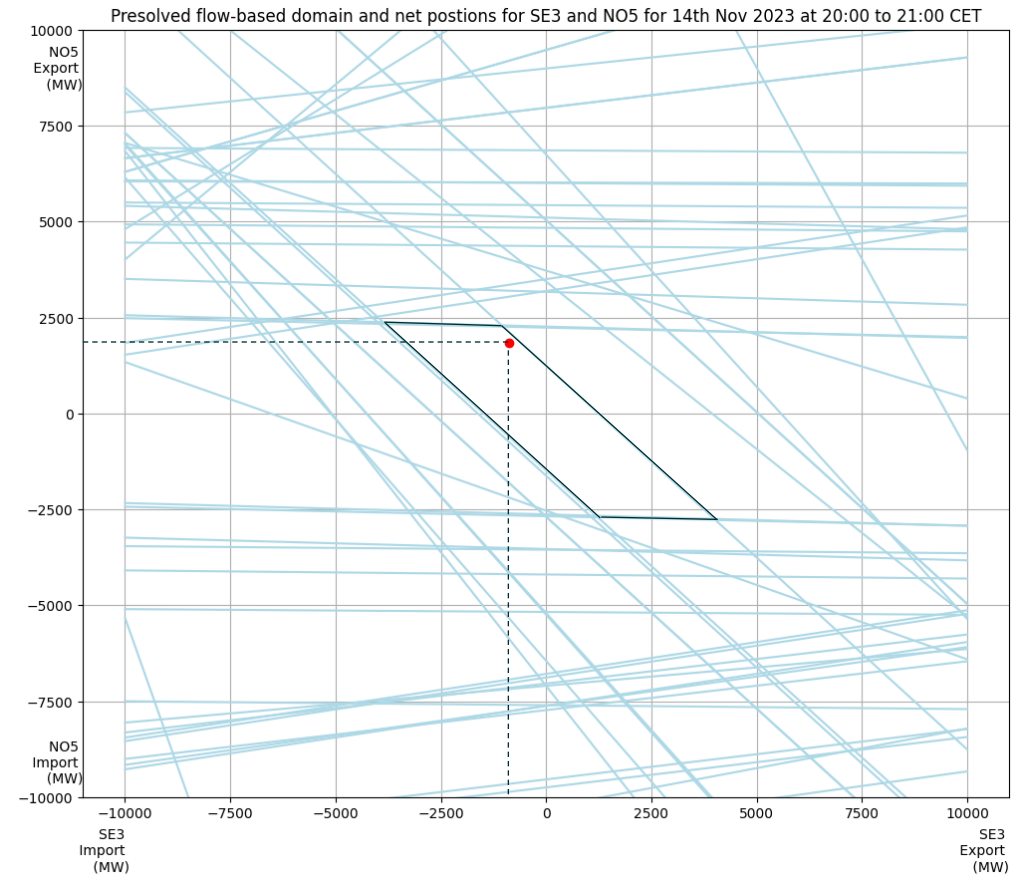
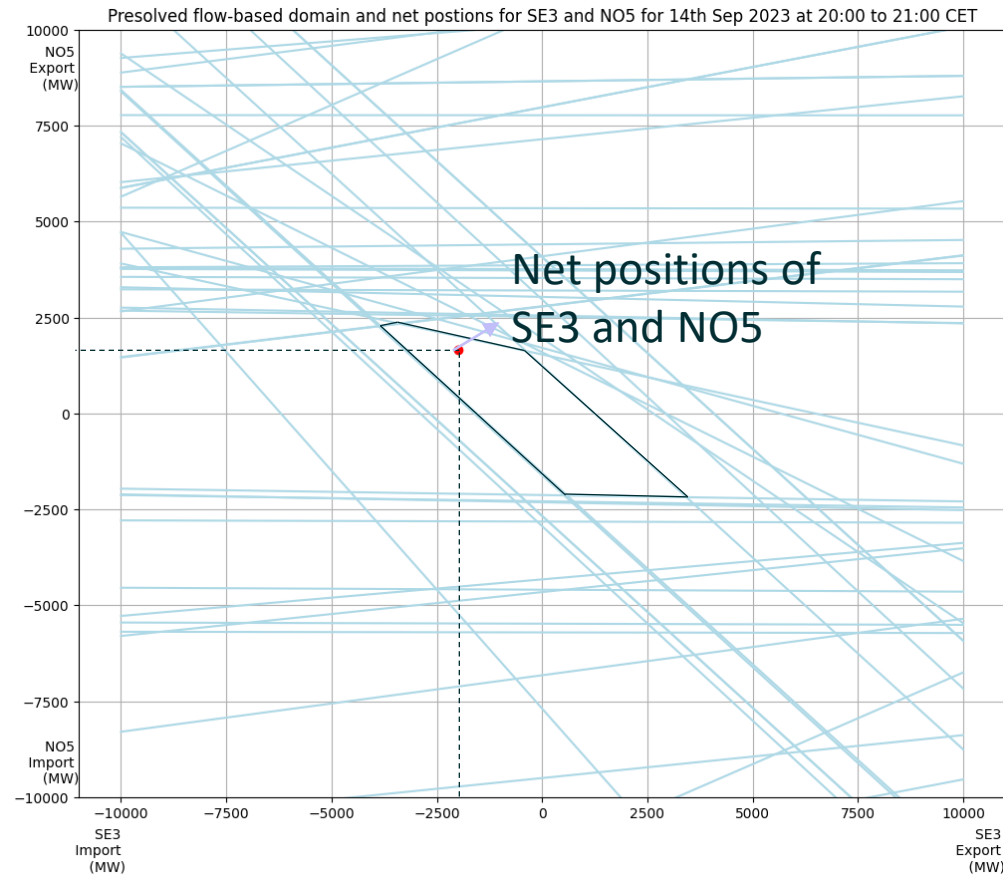
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Ternary plots for decomposition of margins in the Nordics



1. Visualizing flow-based domains

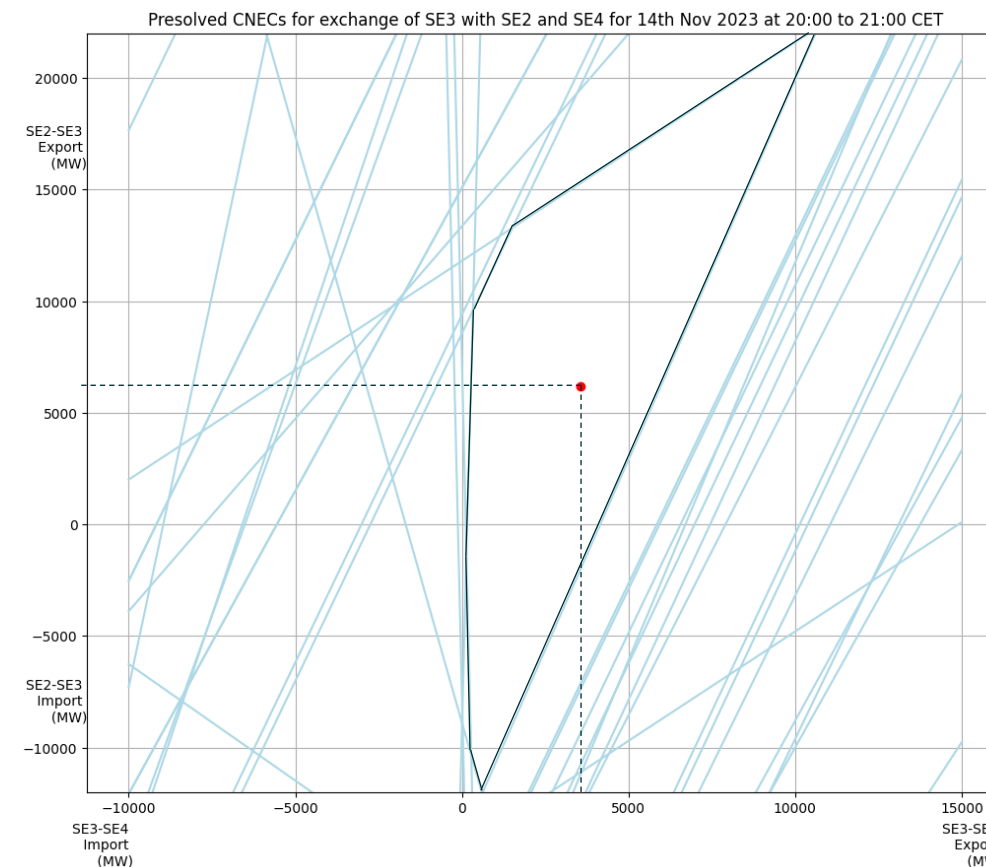
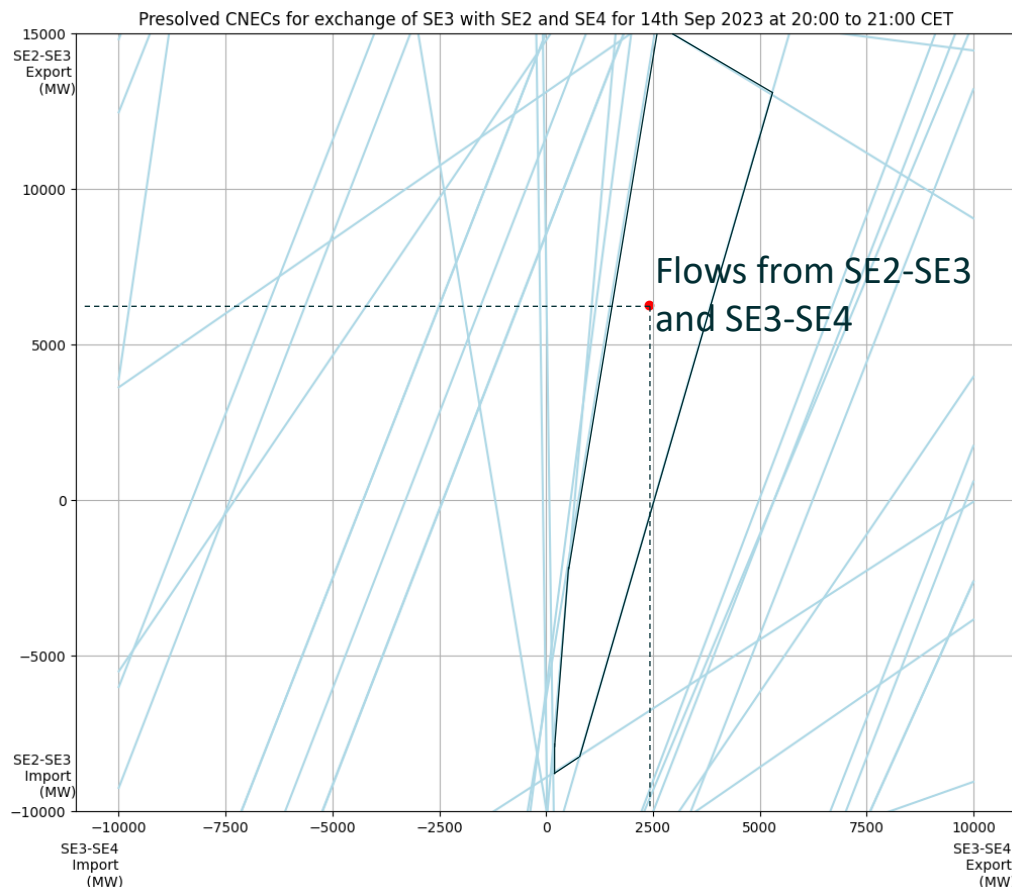
Presolved flow-based domain and net positions for SE3 and NO5



- PTFDs of SE3 and NO5 and RAMs published for each non-redundant presolved CNEC is used to obtain the above flow-based domains.
- It is one of the 930 ($n*(n-1)$) combinations possible for this hour
- The net positions of SE3 and NO5 are indicative of the market outcome from parallel runs.

2. Visualizing flow-based domains

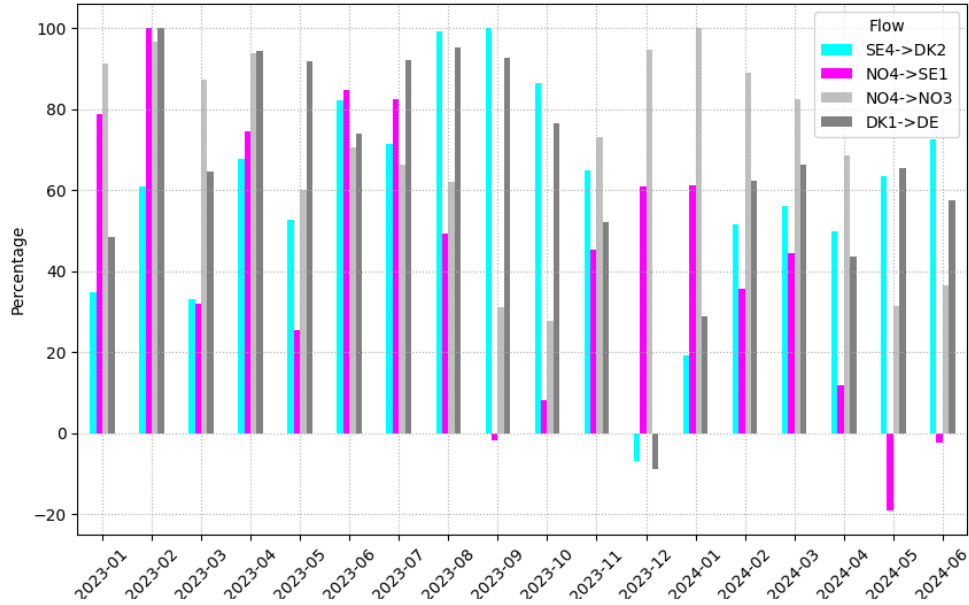
Presolved flow-based domain and scheduled exchanges between SE2-SE3 and SE3-SE4.



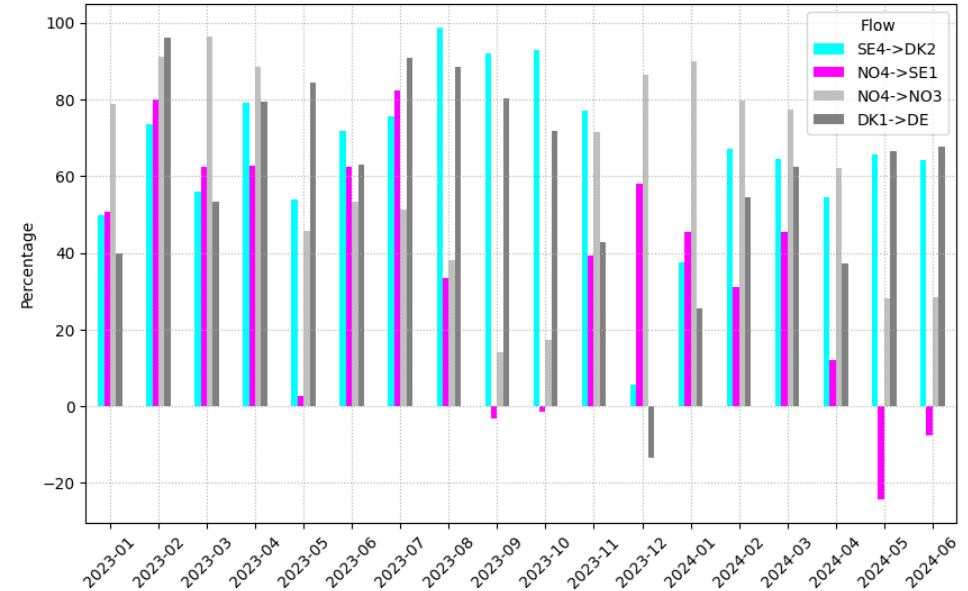
- The zone-to-zone PTDFs are useful in creating the flow-based domain for set of borders which gives the bilateral scheduled exchanges.
- The total number of cross-border lines would be 37. Therefore, it results in a 37-dimensional space for visualising the flow-based method for exchanges.

Comparison of Average percentage flows

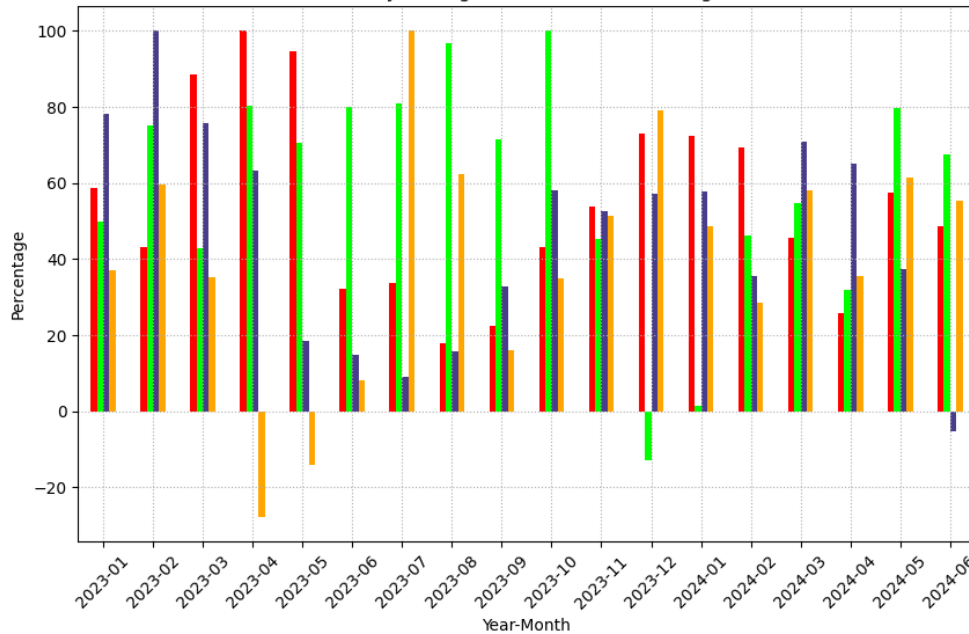
Monthly Average Flows FBMC (Percentage)



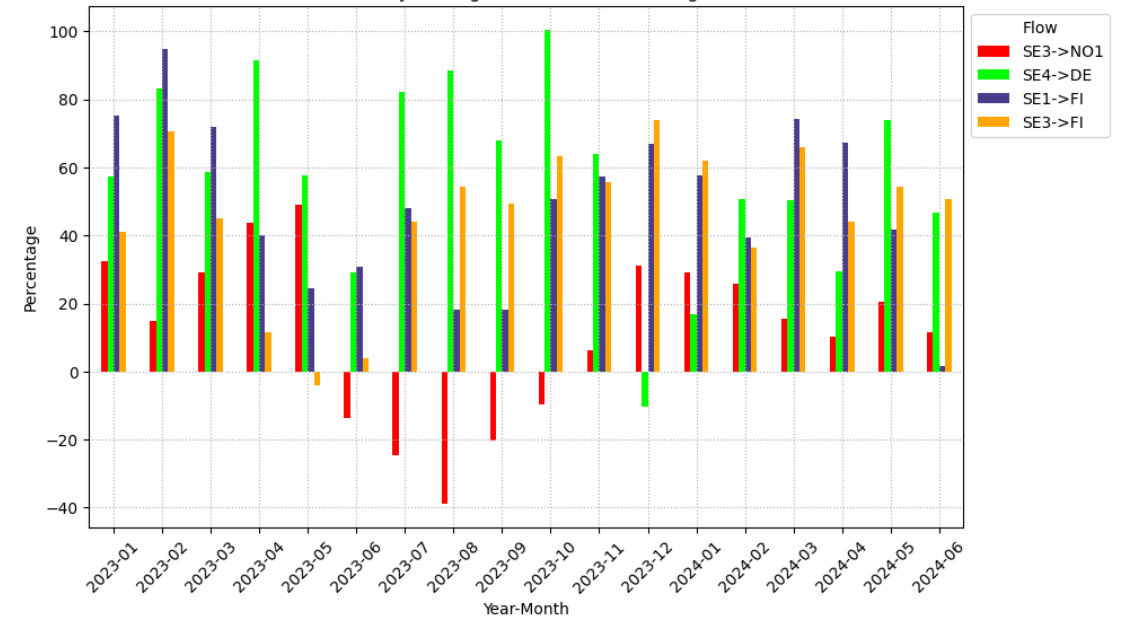
Monthly Average Flows ATC (Percentage)



Monthly Average Flows FBMC (Percentage)



Monthly Average Flows ATC (Percentage)

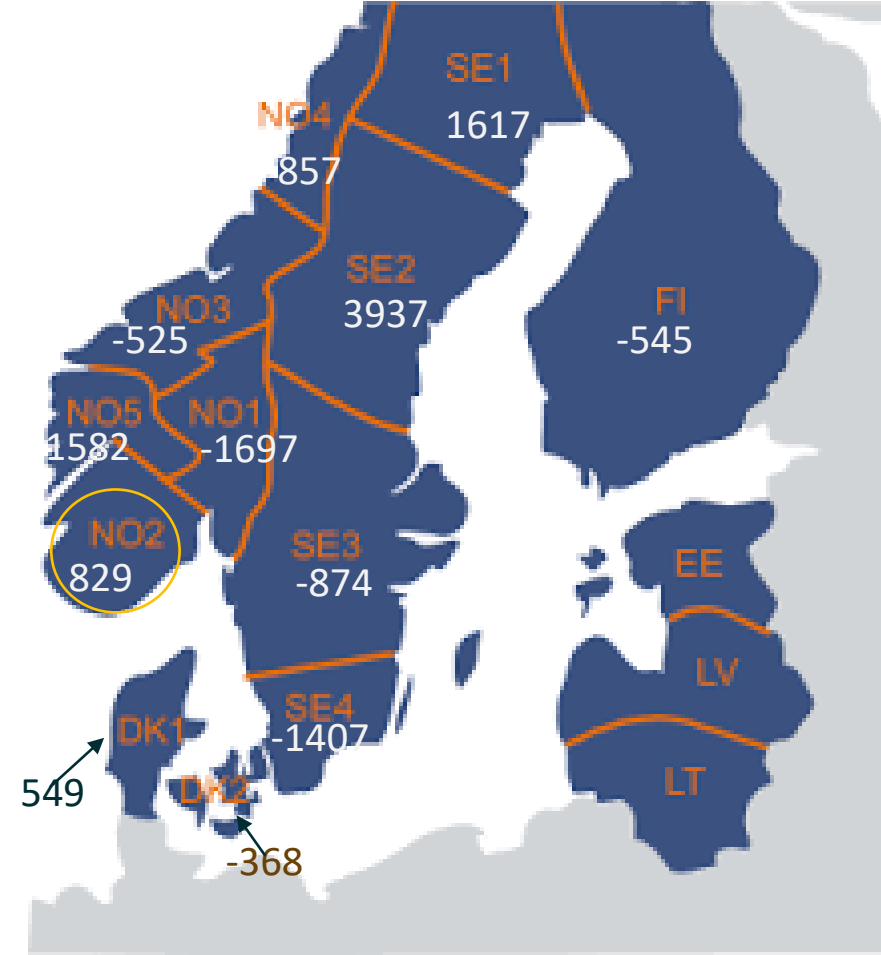


Comparison of Average net positions

Average Net positions: FBMC



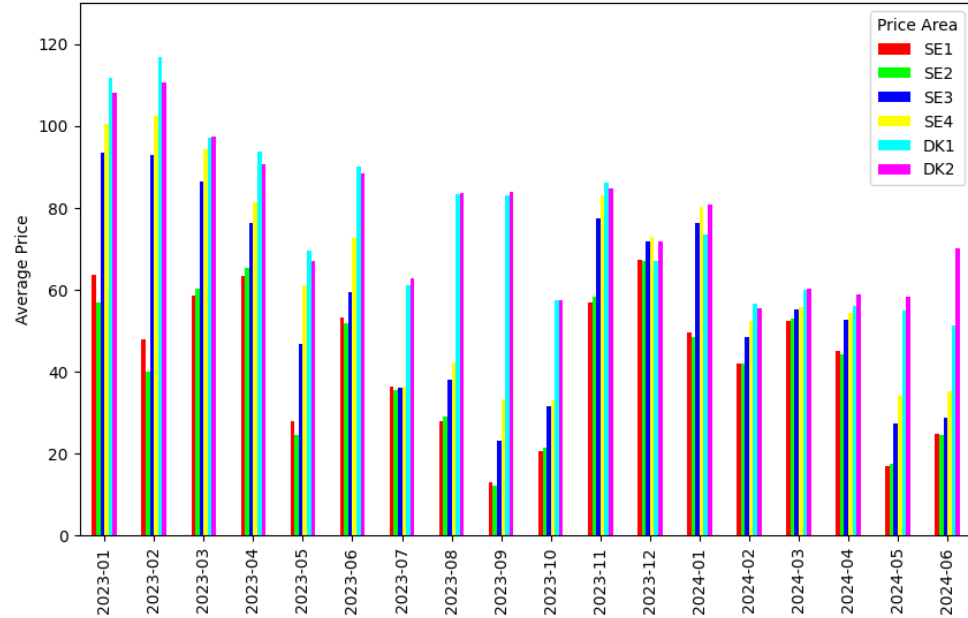
Average Net positions: ATC



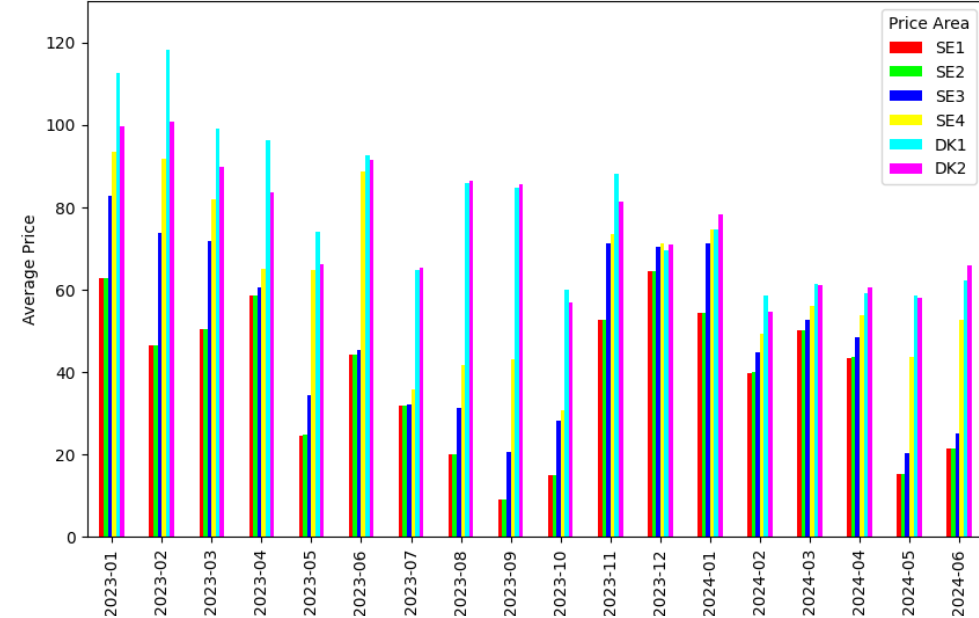
Significant change in NO2 position can be explained by increased flows from NO1 to NO2 due to FBMC.

Comparison of average monthly prices

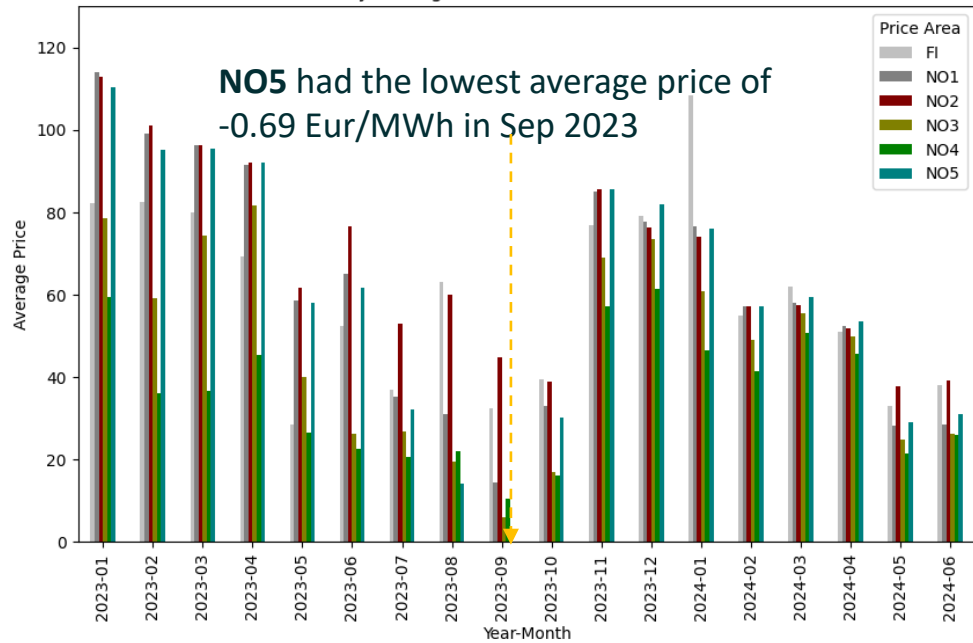
Monthly Average Prices for Each Price Area in FB



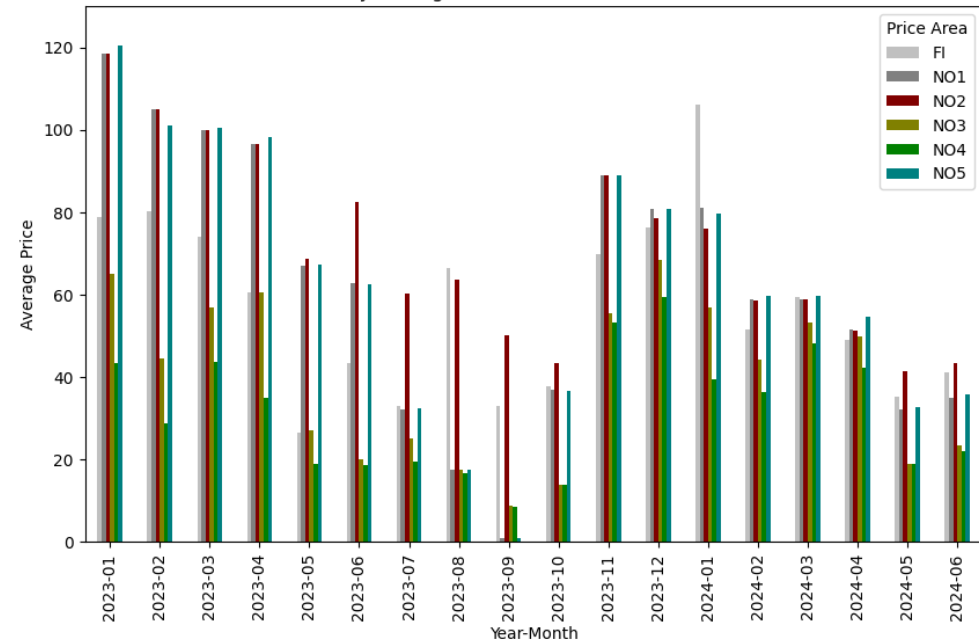
Monthly Average Prices for Each Price Area in ATC



Monthly Average Prices for Each Price Area in FB



Monthly Average Prices for Each Price Area in ATC



Comparison of Average price spreads

Bidding zones combination	Average Price spread in FBMC	Average Price spread in ATC
FI->NO4	25.1	28.3
FI->SE1	17.6	19.1
FI->SE3	2.3	7.3
NO1->NO2	-6.1	-8.7
NO1->NO3	15.8	25.4
NO1->NO5	2.3	-0.3
NO1->SE3	4.5	13.7
NO2->NO5	8.3	8.3
NO3->NO4	11.5	9.2
NO3->NO5	-13.5	-25.7
NO3->SE2	5.2	0
NO4->SE2	-6.3	-9.2
DK1->DK2	-1.2	3.5
DK1->SE3	18.5	28.6
DK2->SE4	14	13.2
SE1->NO4	7.5	9.1
SE1->SE2	1.1	0
SE2->SE3	-16.5	-11.7
SE3->SE4	-5.7	-12
DK1->NL	-9.6	-7.4

Marginal value of flow between bidding zones i and j is given by:

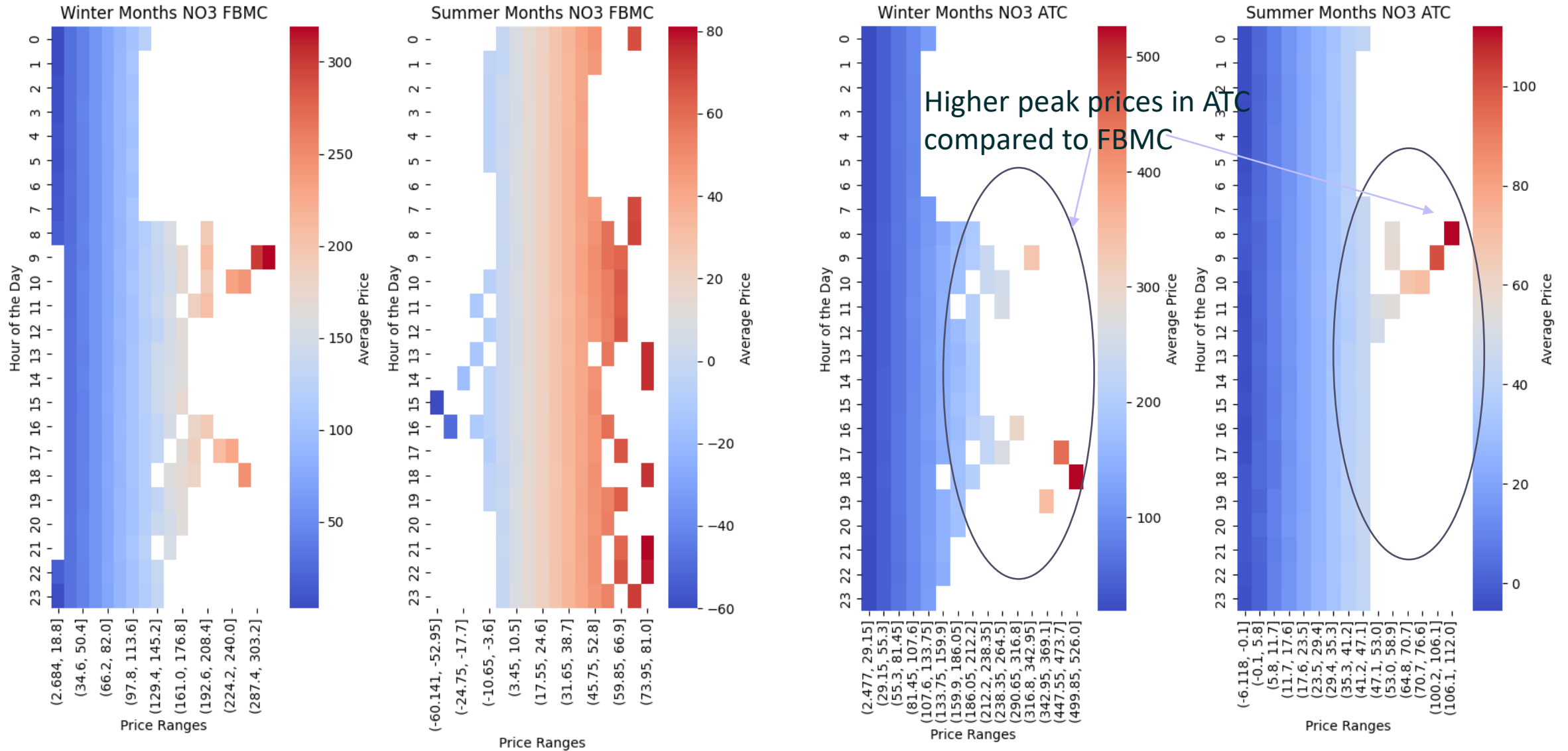
$$(P^j - P^i) = \sum_n \rho_n * PTDF_n^{ij}$$

Price differences between bidding zones i and j

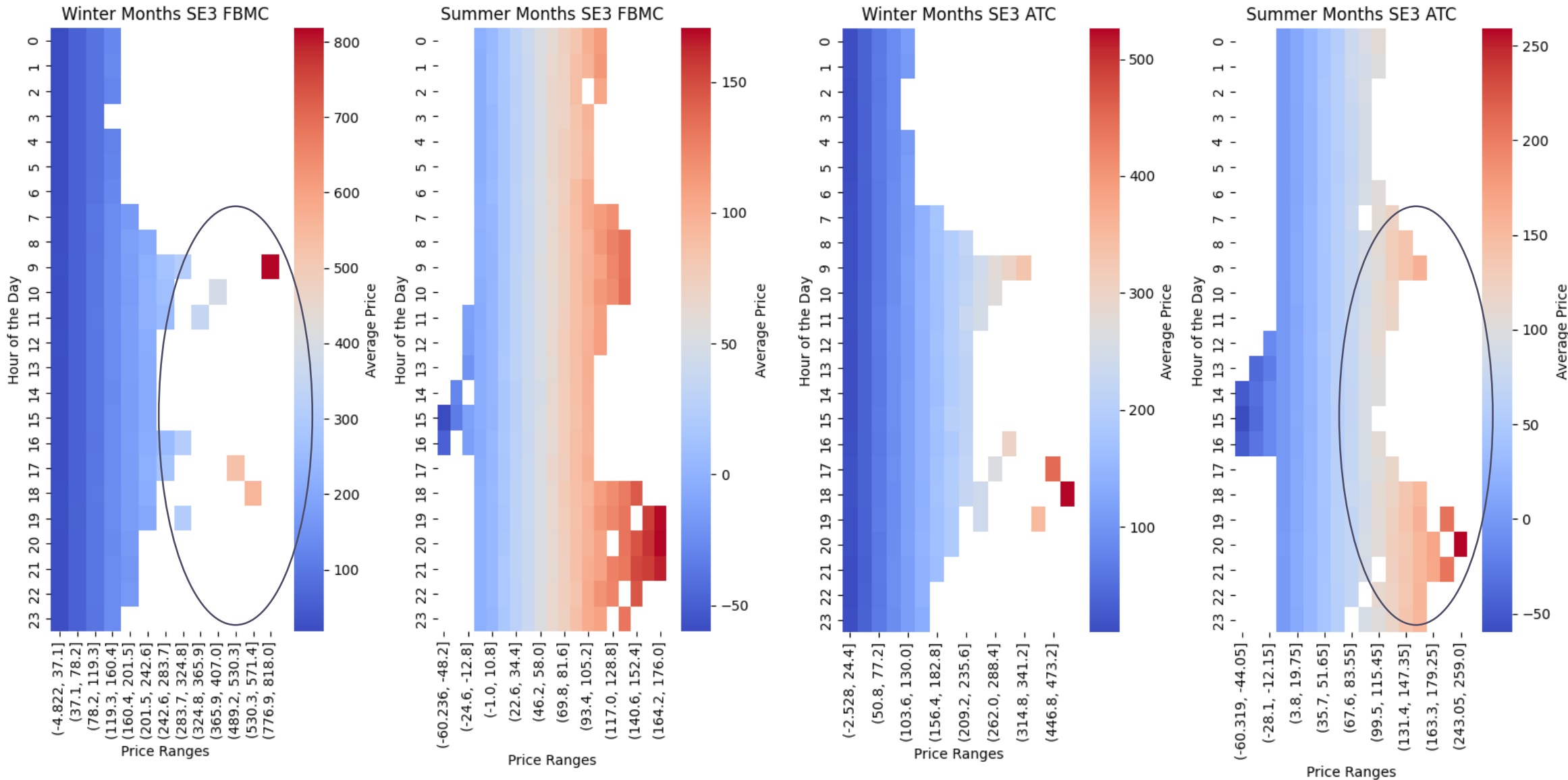
Zone-to-zone PTDF for zone i - zone j on CNE n

- The price differences reduce in FBMC compared to ATC on most bidding zone border combinations.
- Indicating that FBMC is more efficient in allocating capacities, compared to the ATC method, leading to more price convergence

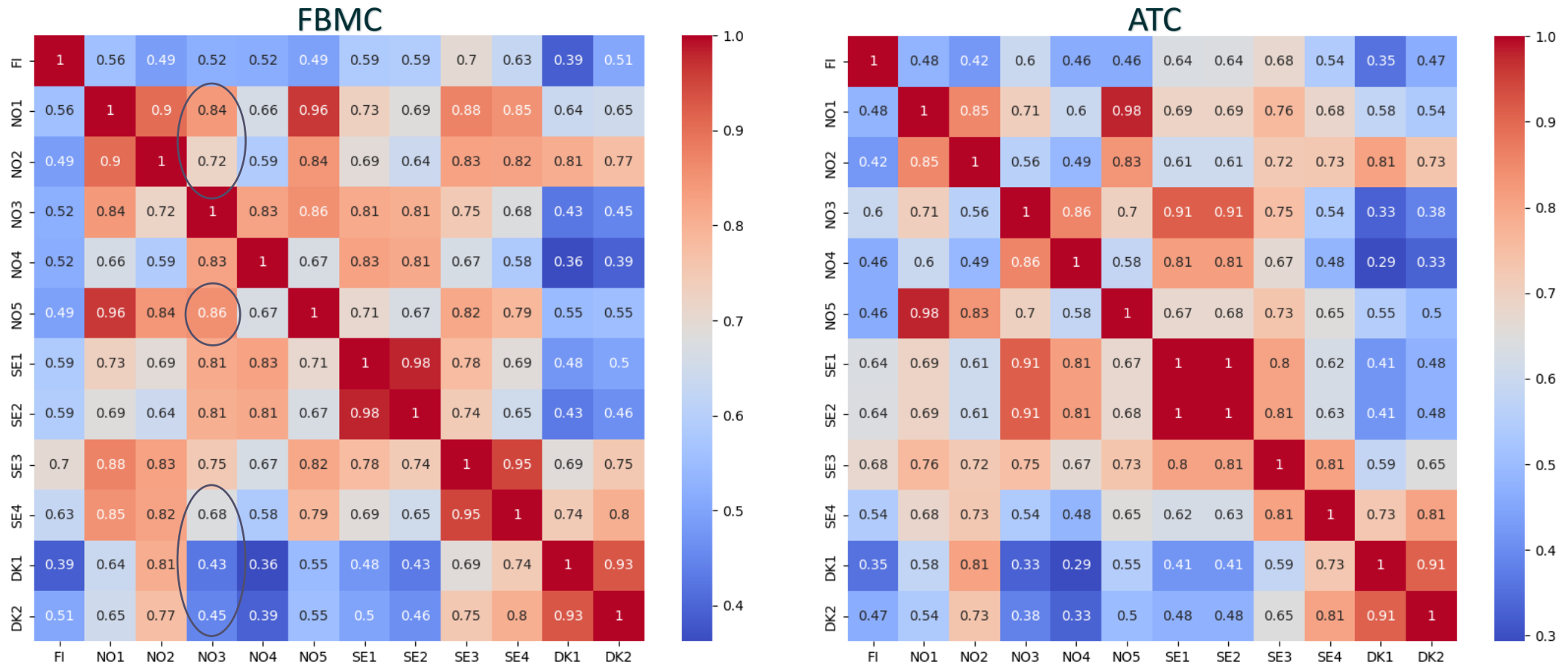
Seasonal pattern of hourly price variations in NO3



Seasonal pattern of hourly price variations in SE3



Price correlation with FBMC and ATC methods



- The price correlation increases with FBMC in most cases but not all.
- For NO3, the correlation with SE1, SE2 and NO4 reduces while it improves with SE4, NO1, NO2, NO5.
- NO1 and NO5 seem to get higher correlation with SE3 and SE4 in the FBMC.
- DK1 and DK2 also have more correlation with the Norwegian zones in the FBMC compared to ATC.

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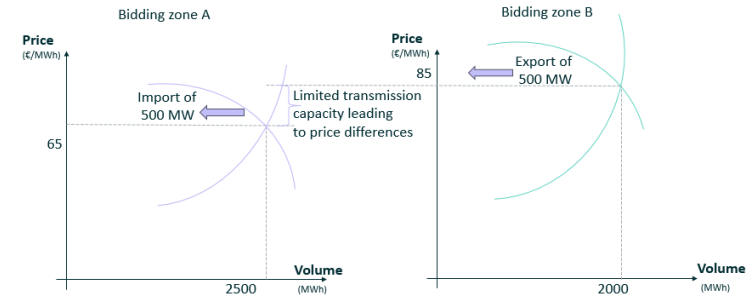
Some topics for further discussions

Price differences, Counterintuitive flows, Hydro water values, Reduced intraday capacities, Balancing market costs

Hydropower strategy

- Water values determined by the reservoir content and varies with the time of the year.
- Depending on the comparison of water values with market price, the strategy is determined to either discharge the water now or save it for later.
- High water value than market price: save water from reservoir now
- Low water value than market price: produce more now
- In FBMC, due to getting higher transmission capacities, the water values will have to be increased to not empty the reservoir and so on.

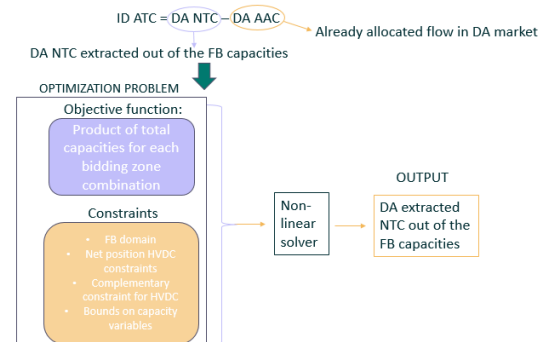
Non-intuitive flows



- Flow from high price to low price zone from Flow-based optimization to relieve congestion on grid elements.
- These flows can contribute to the overall social welfare by relieving more capacities in the grid.

Intraday capacities after FB go-live in DA

- Intraday ATC is needed for the ID auction and cross-border continuous intraday trading.
- This method is called Available Transfer Capacity Extraction (ATCE).



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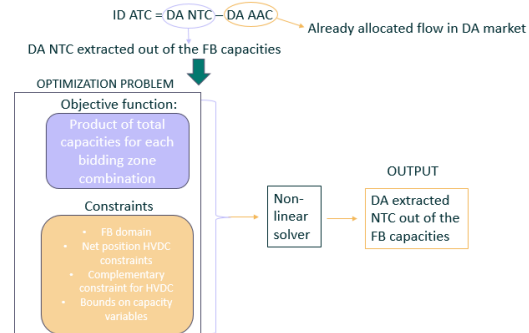
Non-intuitive flows



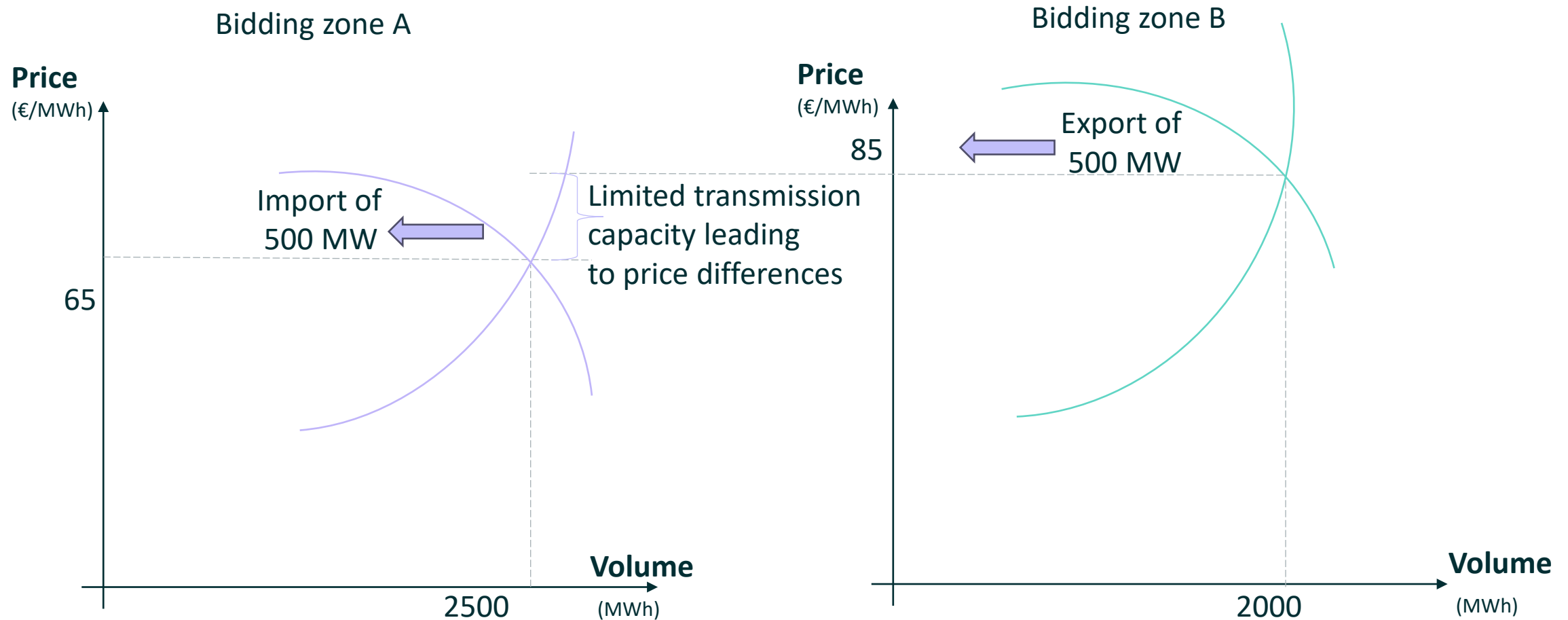
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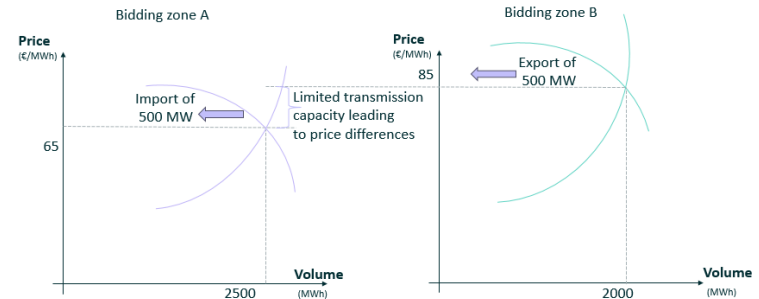
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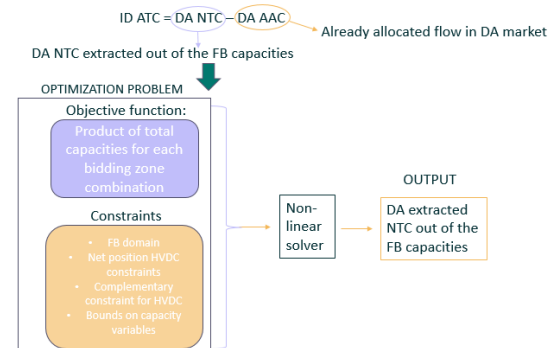
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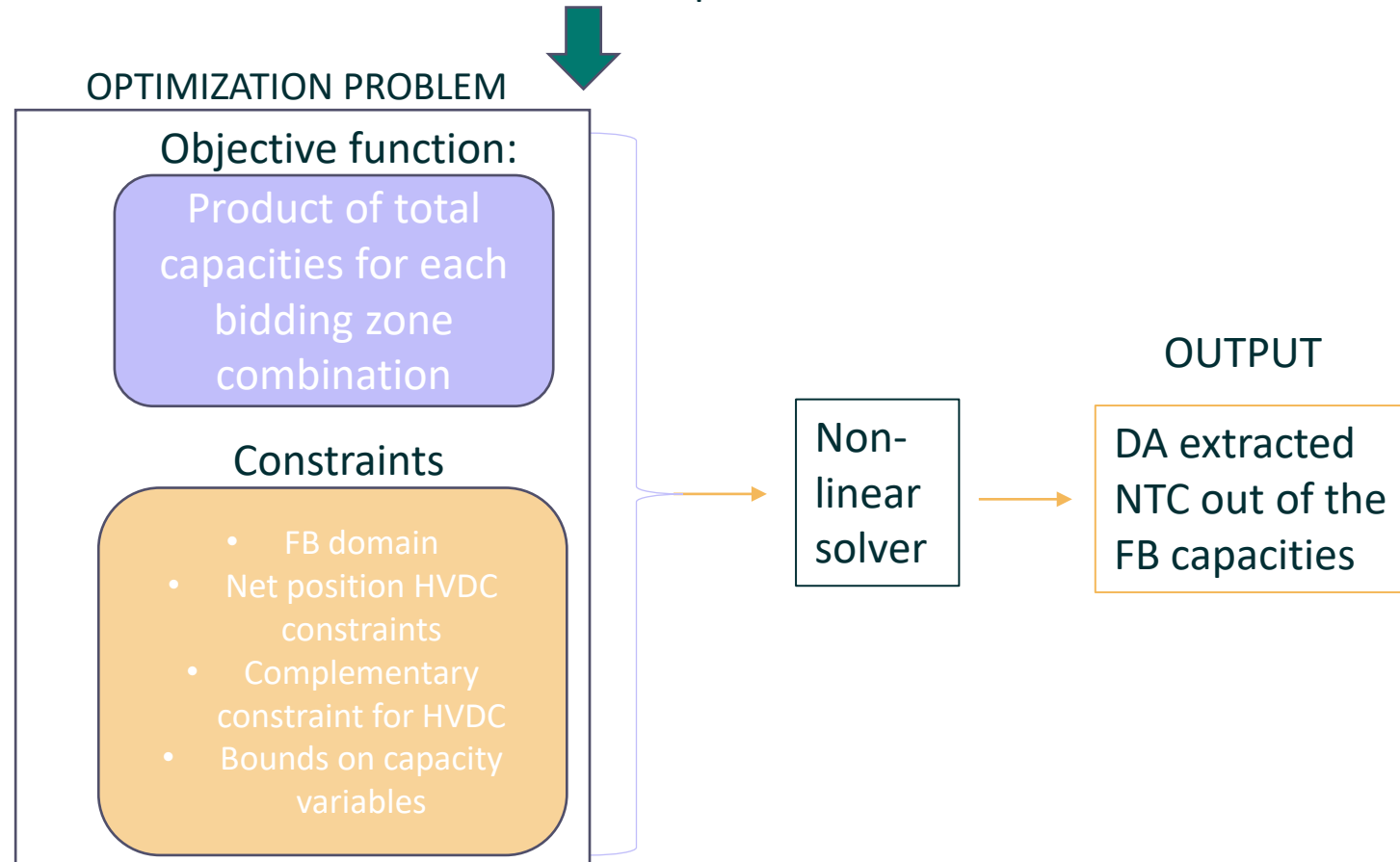
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- Intraday ATC is needed for the ID auction and cross-border continuous intraday trading.
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$$\text{ID ATC} = \text{DA NTC} - \text{DA AAC}$$

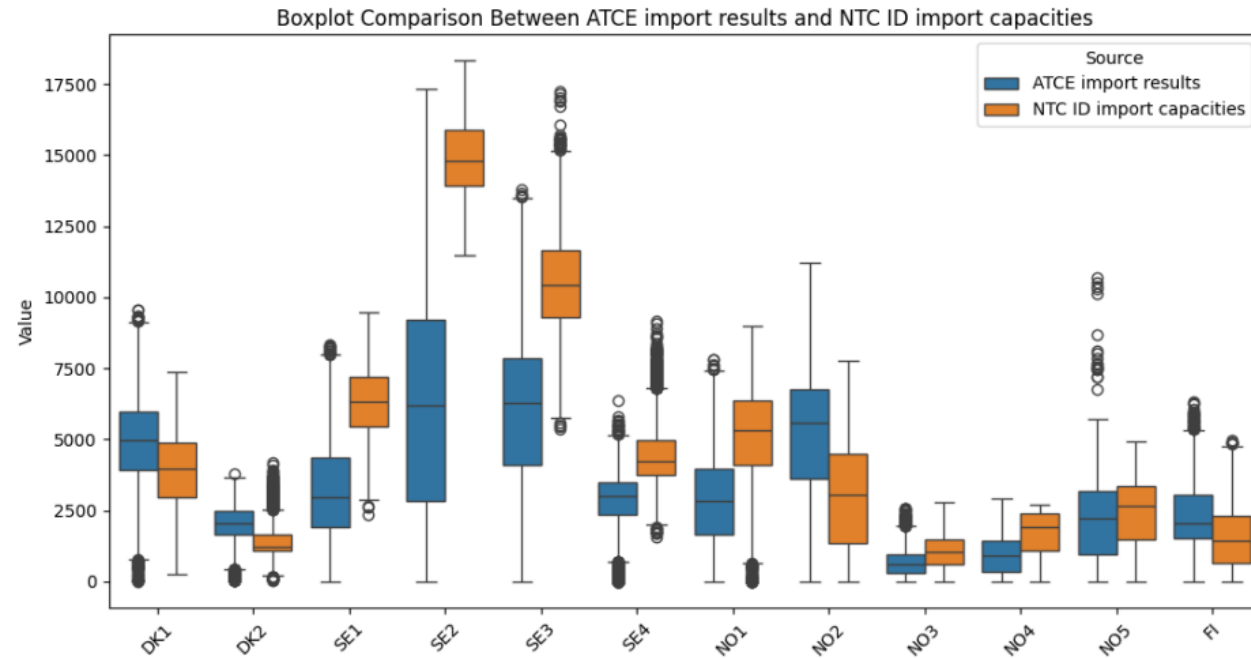
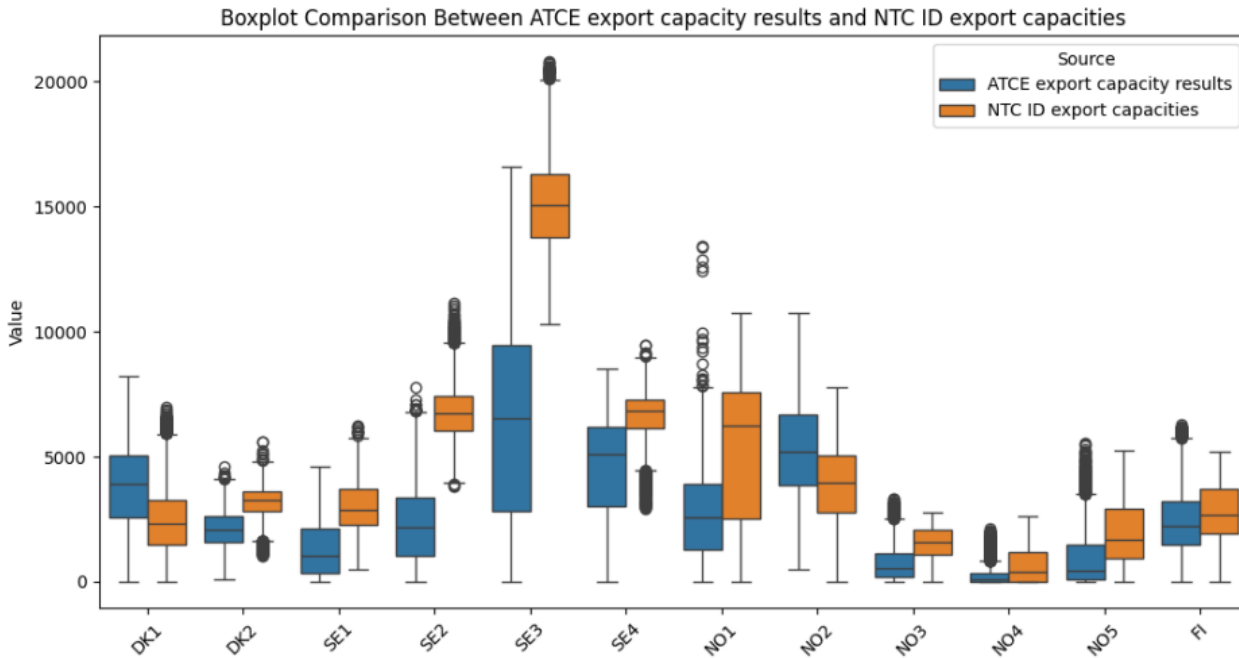
Already allocated flow in DA market

DA NTC extracted out of the FB capacities



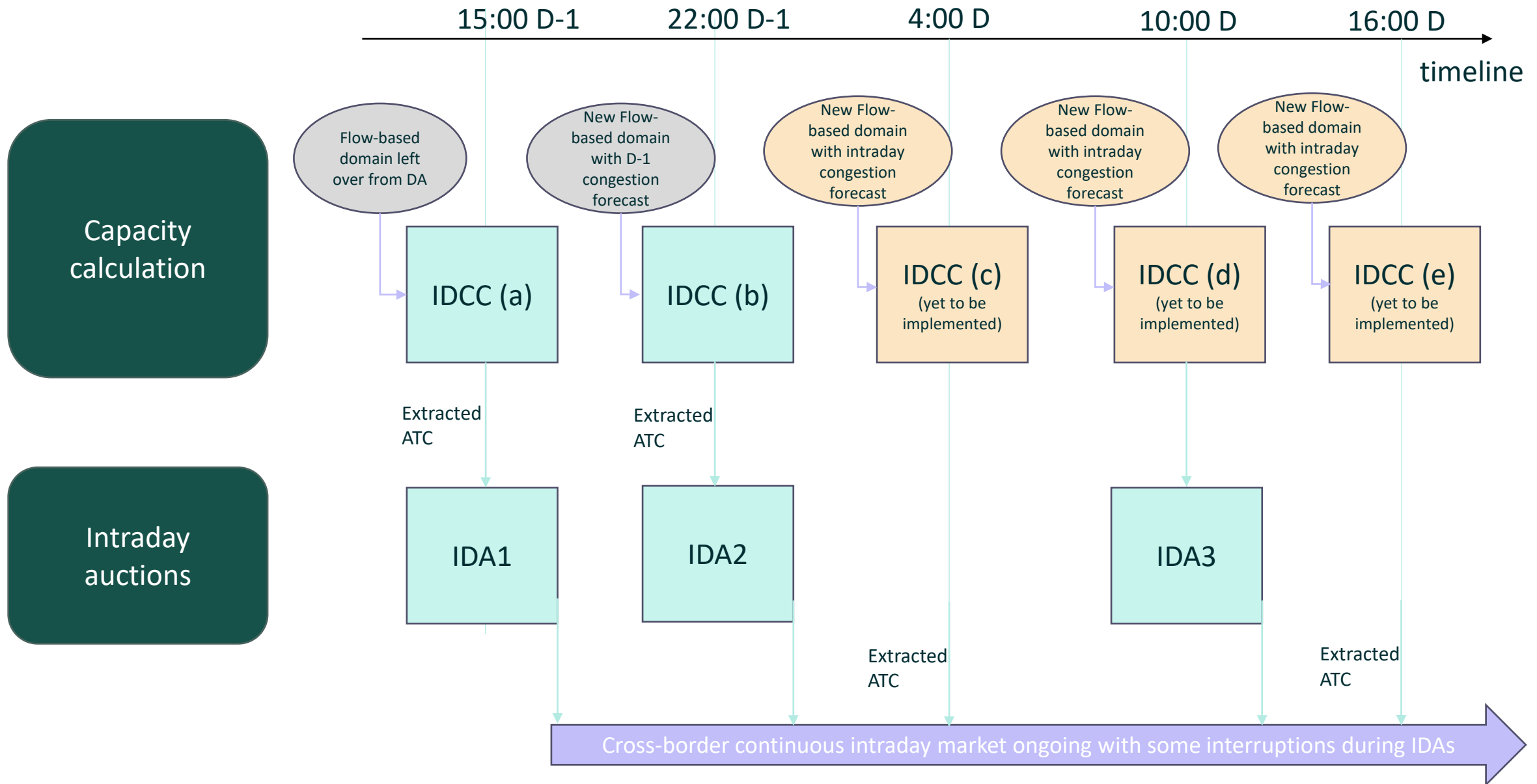
Intraday capacities after FB go-live in DA

Comparison based on ATCE results from week 26 2023 until week 13 2024



- ID capacities in some countries are much higher today than the ATCE results, for example, in Sweden.
- Large intraday capacities allocated without physical consideration could lead to overloads which need to be resolved by TSOs (could be more expensive).
- ATCE takes these situations into account.

Intraday Capacity Calculation in Core region



Note: Boxes with color are yet to be implemented

1. Market timeline and competition

2. Introduction to Market Coupling

3. Connection to the physical grid

4. Results from Nordic
flow-based parallel runs

5. Topics for further discussions

6. Conclusion

6. Conclusion

Conclusion

