IPN VannFly
Flow-based market clearing
Brukermøte 2023

Sintef Energy Research

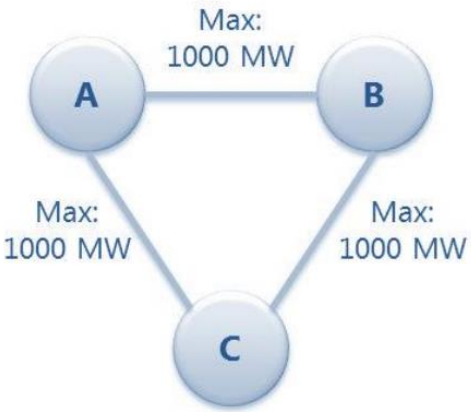
Energy systems

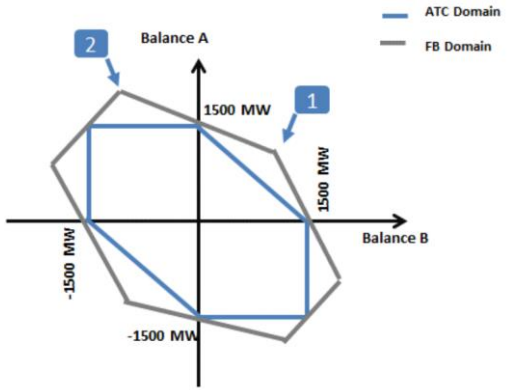
VannFly – The value of grid information in flow-based market clearing

Bakgrunn:
De nordiske TSOene planlegger å innføre flyt-basert markedsklærering (FBMC) i det nordiske kraftmarkedet. Mens metode bidra til å utnytte det eksisterende transmisjons-system, krever det ekstra informasjon og tilpasset metoder for prisprognosering og –produksjonsplanlegging.

Mål:
Målet med prosjektet er å finne ut hva er konsekvens av introduksjon av FBMC i det nordiske system, hvilke type informasjon markedsdeltaker trenger og hvordan FBMC skal hensyntas i langtidsstrategi for vannkraftprodusenter

Metode:
Prosjektet gjør baserer seg på en litteraturstudie, oppfølging av den pågående prosessen hos Nordic CCM, implementasjon i våre LTM prototype modeller, samt en rekke case analyser.





Type: IPN

Ansvarlig organisasjon: TrønderEnergi

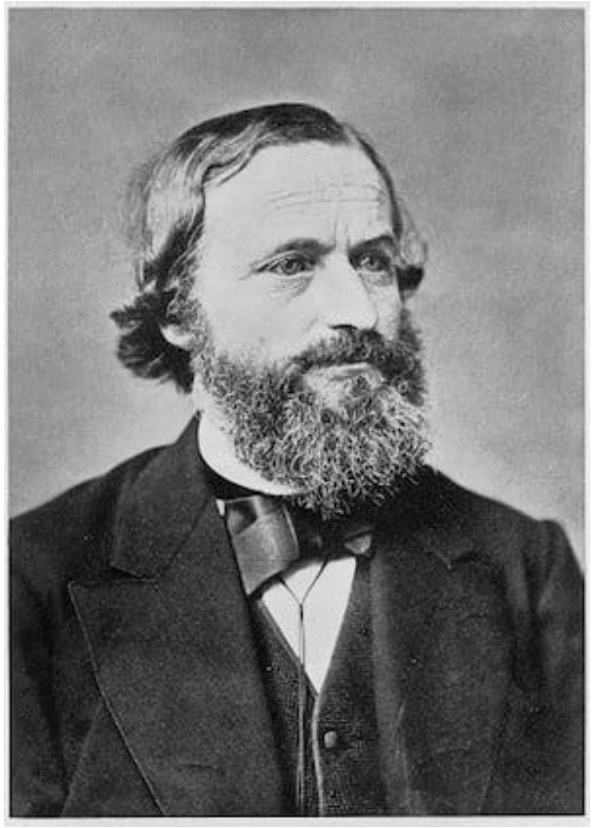
Partnere: Statkraft, Hafslund Eco, Lyse Produksjon, Agder Energi, Statnett

Prosjektperiode: 2020 - 2023

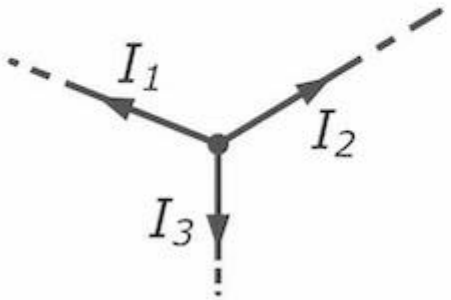
Totalt budsjett: 9 020 000 MNOK

SINTEF Energi: 8 200 000 MNOK

Kontaktperson: Dr. Stefan Jaehnert

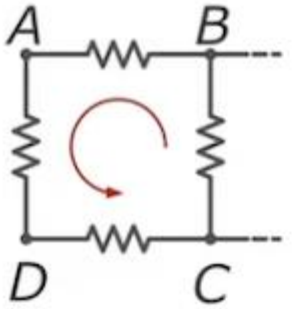


"The sum of all currents leaving a node in any electrical network is always equal to zero."



$$\sum_{i=1}^{n} I_i = I_1 + I_2 + I_3 = 0$$

"The the sum of the voltage rises and voltage drops over all elements in a closed loop is equal to zero."



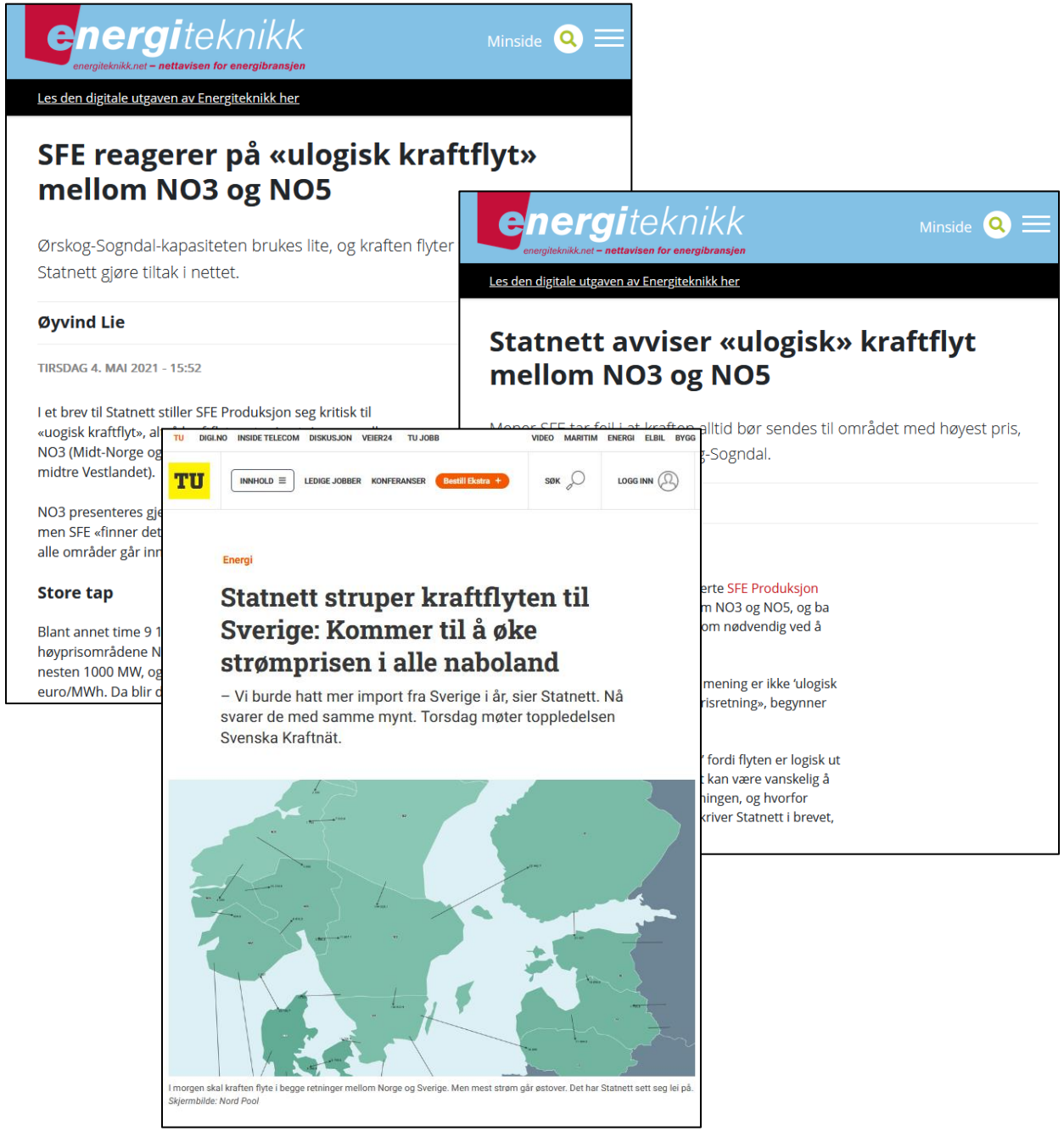
$$\sum_{i=1}^{n} V_i = V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Source: https://www.allaboutcircuits.com/news/historical-engineer-gustav-kirchhoff-voltage-current-spectroscopy/

Background

Examples:

- Utilisation of Ørskog-Fardal power line
  - Flow against price gradient observed and negative NTC
- Available capacity on the corridor SE3 – NO1
  - NTC requires definition of a sum restrictions
- Statnett:
  "Det viktigste tiltaket for å få til bedre utnyttelse av nettet er ifølge Statnett innføring av flytbasert markedsklarering. «Dette vil gjøre at de fysiske forutsetningene i nettet går direkte inn i markedsløsningene. Dette vil gi både gi mer flyt og riktigere priser»."



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energiteknikk.net – nettavisen for energibransjen
Minside
Les den digitale utgaven av Energiteknikk her

SFE reagerer på «ulogisk kraftflyt» mellom NO3 og NO5

Ørskog-Sogndal-kapasiteten brukes lite, og kraften flyter
Statnett gjøre tiltak i nettet.

Øyvind Lie

TIRSDAG 4. MAI 2021 - 15:52

I et brev til Statnett stiller SFE Produksjon seg kritisk til
«uogisk kraftflyt», al
NO3 (Midt-Norge og
midtre Vestlandet).

NO3 presenteres gj
men SFE «finner det
alle områder går inn

Store tap

Blant annet time 9 1
høyprisområdene N
nesten 1000 MW, og
euro/MWh. Da blir d

energiteknikk
energiteknikk.net – nettavisen for energibransjen
Minside
Les den digitale utgaven av Energiteknikk her

Statnett avviser «ulogisk» kraftflyt mellom NO3 og NO5

alltid bør sendes til området med høyest pris,
-Sogndal.

erte SFE Produksjon
m NO3 og NO5, og ba
om nødvendig ved å

mening er ikke 'ulogisk
risretning», begynner

fordi flyten er logisk ut
kan være vanskelig å
ingen, og hvorfor
kriver Statnett i brevet,

TU DIGI.NO INSIDE TELECOM DISKUSJON VEIER24 TU JOBB VIDEO MARITIM ENERGI ELBIL BYGG
TU INNHOLD LEDIGE JOBBER KONFERANSER Bestill Ekstra SØK LOGG INN

Energi

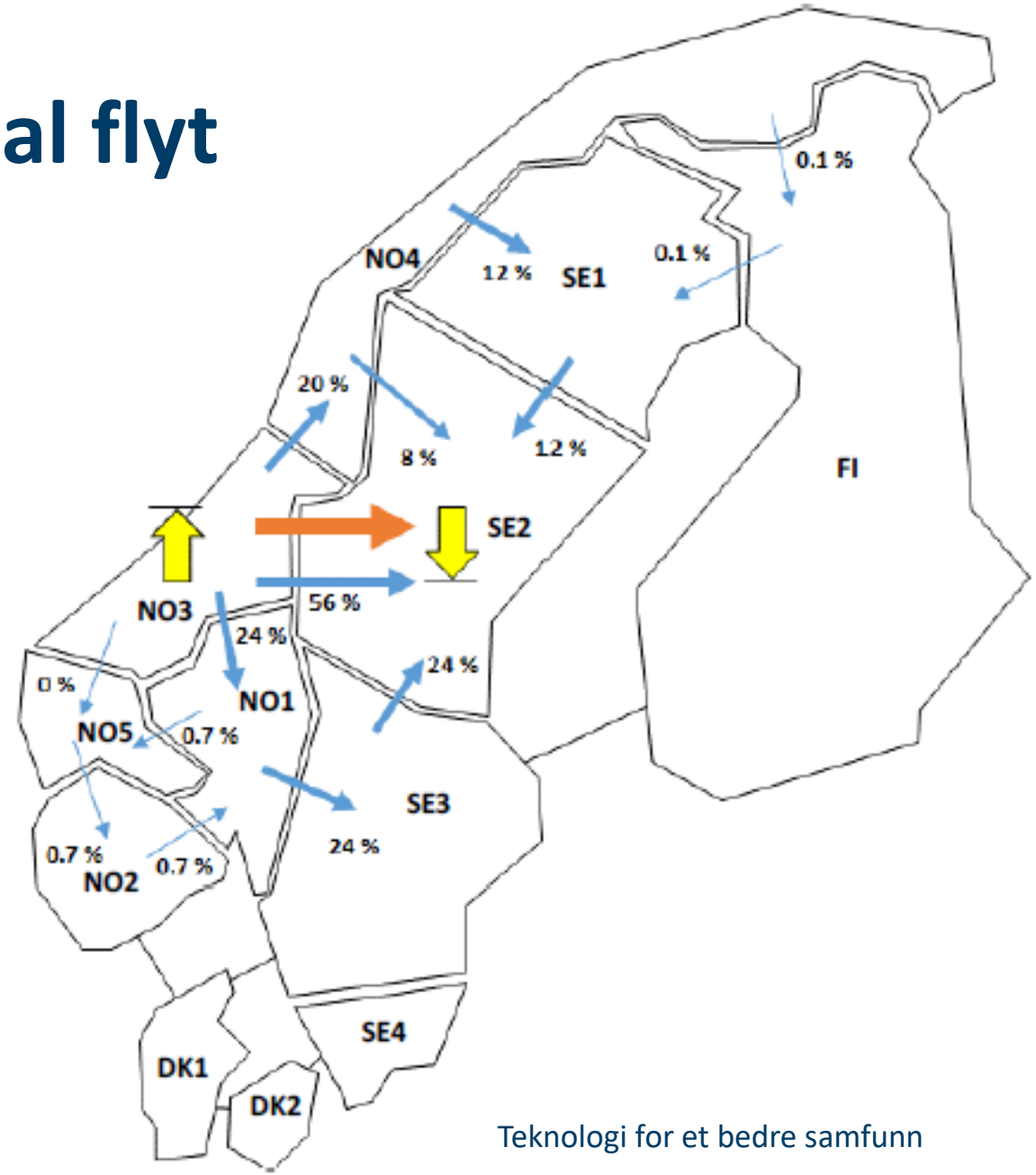
Statnett struper kraftflyten til Sverige: Kommer til å øke strømprisen i alle naboland

– Vi burde hatt mer import fra Sverige i år, sier Statnett. Nå svarer de med samme mynt. Torsdag møter toppledelsen Svenska Kraftnät.

I morgen skal kraften flyte i begge retninger mellom Norge og Sverige. Men mest strøm går østover. Det har Statnett sett seg lei på.
Skjermbilde: Nord Pool

Market flow vs. physical flyt

- Market flow goes directly from area A to area B
  - Always from an area with low price to an area with a high price
- Physical flow divides on all possible paths from area A to area B
  - Power Transfer Distribution Factors (PTDFs) describes how much of the flow that goes on each line
- Flow-Based Market Coupling:
  - Constraint on physical flow instead of market flow



Formulation NTC and FBMC

NTC formulation: Objective function: Maximize welfare economic surplus

- Subject to energy balance in each area
  (Production – Demand + Import – Export = 0)
- Subject to NTC constraints

FB formulation: Objective function: Maximize welfare economic surplus

- Subject to energy balance in each area
  (Production – Demand + Import – Export = 0)
- Subject to FB constraints

Equations

PS – producer surplus
CS – consumer surplus
CR – congestion rent
NP – net position
ATC – available transfer capacity
PTDF – power transfer distribution factor
RAM – remaining available margin

NTC:

- Max Σ(PS + CS + CR)

subject to:

- $NP \leq \Sigma_j ATC_j$ (Export)
- $NP \geq \Sigma_j -ATC_j$ (Import)
- $\Sigma NP = 0$

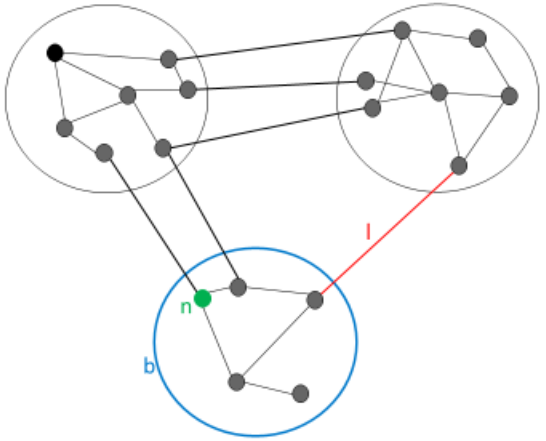
FB:

- Max Σ(PS + CS + CR)

subject to:

- $PTDF * NP \leq RAM$
- $\Sigma NP = 0$

The Flow-Based Constraint



b – bidding zone
n – node
l – critical network element

A critical network element (**CNE**) is a network element that the TSO requires to monitor for potential overloads.

FB constraint for each CNE:

$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{\lim}$$

GSK

Forecast

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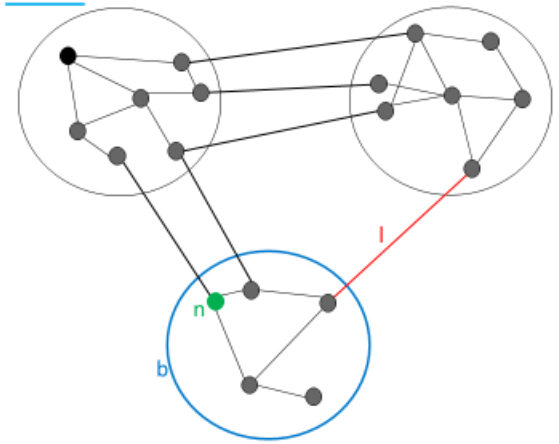
From Nodal PTDFs to Bidding Zone PTDFs using Shift Keys



The Generation Shift Key (**GSK**) is a value used in the translation from node-to-CNE PTDFs to zone-to-CNE PTDFs.

$$PTDF_l^b = \sum_{n \in N_b} GSK^n \times PTDF_l^n$$

$PTDF_l^b$	PTDF for zone b on CNE l ("Zonal PTDF")
GSK^n	GSK for node n
$PTDF_l^n$	PTDF for node n on CNE l ("Nodal PTDF")
N_b	Number of nodes in zone b

In our initial version of the FB procedure, we are opting for a flat GSK strategy. However, the outcome of the flow predictions from different GSK strategies will be monitored over time, which will give a base for developing a potential better strategy in a later version of the Nordic FB.

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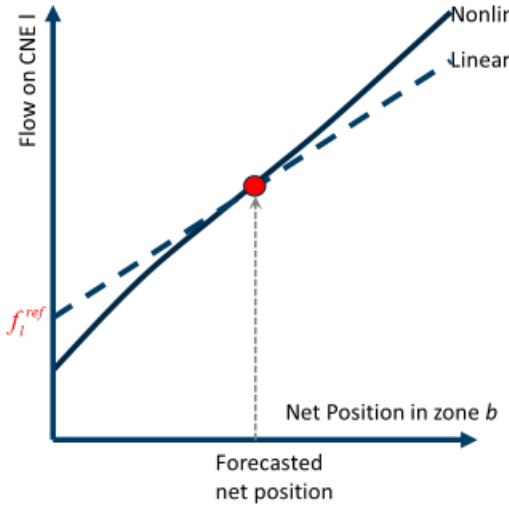
Use of Forecast for Parameter Estimation



$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{\lim}$$

Note that:
- f_l^{ref} depends on forecasted net position
- Both $PTDF_l^b$ and f_l^{ref} depend on GSK strategy
- $PTDF_l^b$ may depend on forecast, depending on GSK strategy

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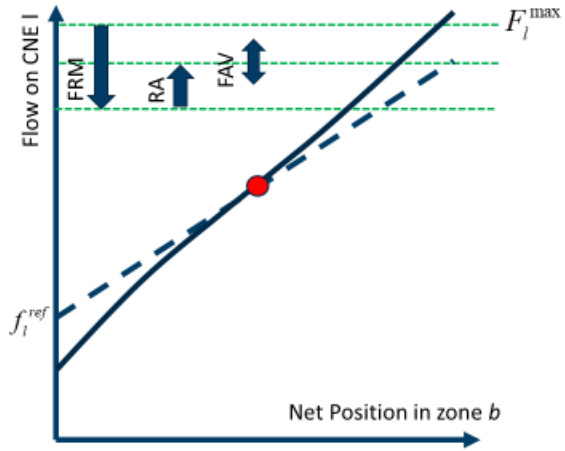
Estimating Flow Limits on CNEs



$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{\lim}$$

$$F_l^{\lim} = F_l^{\max} - FRM_l + RA_l - FAV_l$$

$$RAM_l = F_l^{\lim} - f_l^{ref}$$

$$\sum_{b \in B} PTDF_l^b \times NP^b \leq RAM_l$$

FRM – Flow Reliability Margin (ch 4.8.2)
RA – Remedial Actions (ch 4.9.2)
FAV – Final Adjustment Value (ch 4.9.2)
RAM – Remaining Available Margin

EMPS with FBMC restrictions

NTC vs FBMC

- EMPS
  - NTC based market clearing markedsklarering
  - Transport model with transmission corridors
  - Power flow = import / export on corridor

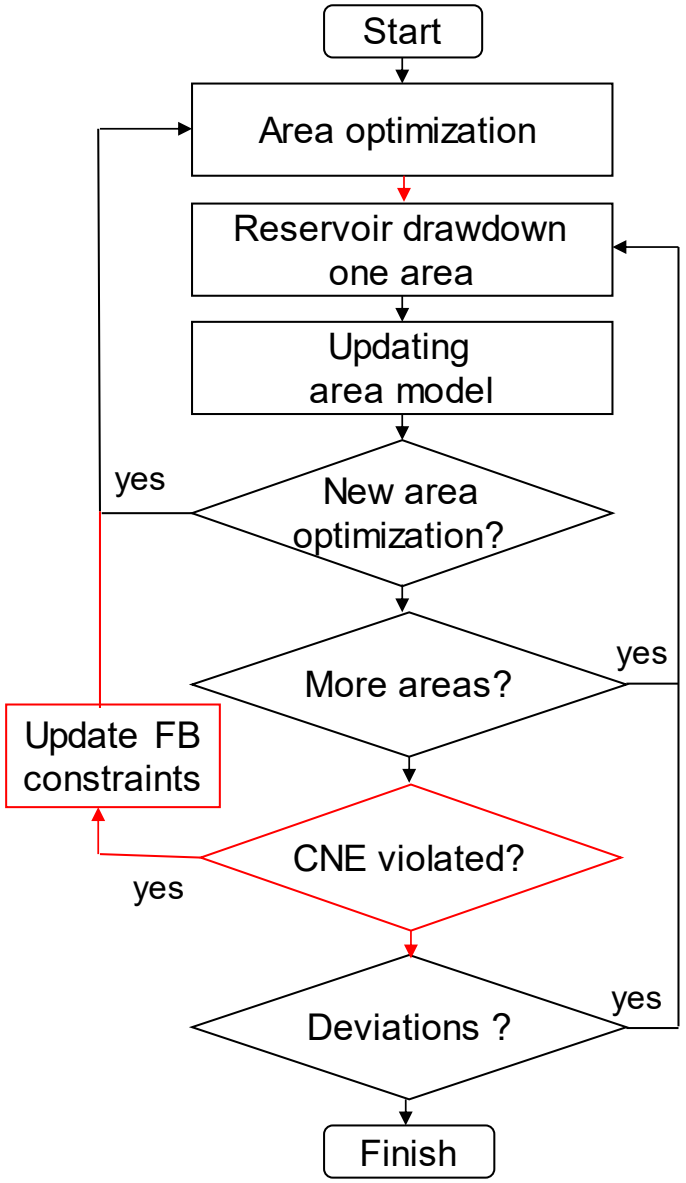
- EMPS with FBMC
  - FB based market clearing
  - Aggregated PTDF description of physical flow
  - Flow depends on net positions throughout the synchronous area

FB implementation in EMPS

Agregated PTDF description:

- Exogenous PTDFs
- PTDF-restrictions are introduced in area optimisation
  - LP-problem

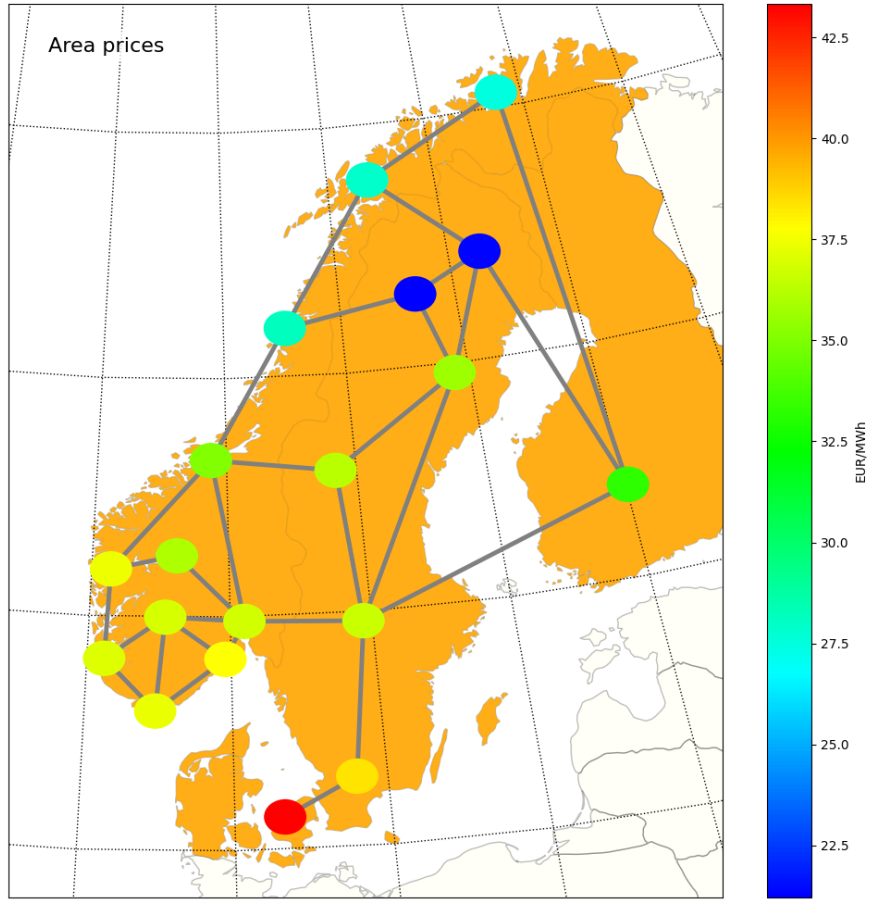
- Restrictions are introduced iterativly:
  - Test on violatoin of restriction => restriction is introduced
  - Identified binding restrictions from the last weeks are introduced from the start



Overview of CNEs in EMPS (based on Jao)

- 376 CNE defined in the dataset
  - 376 CNE*56 time steps = 21056 PTDF restrictions
  - Ca. 8000 restrictions in the original LP
- Ca. 1/3 of CNEs are redundant
- Only ~40 CNEs er bindending under the simulation

CNE	Dualverdi	bindende	Antall
171	-132.8722241	90.23 %	78821
282	-94.31395231	81.25 %	70978
38	-41.36217027	27.87 %	24346
39	-11.04084849	26.80 %	23412
156	-20.58868012	21.51 %	18791
265	-55.48918061	18.37 %	16044
235	-22.03725723	18.34 %	16018
63	-9.723456622	17.64 %	15414
157	-60.3282083	16.99 %	14839
143	-11.69184819	11.03 %	9634
372	-7.228576029	9.69 %	8467
301	-11.48711157	9.19 %	8025
260	-6.410276975	8.64 %	7551
206	-5.337164421	8.27 %	7228
45	-4.467980442	5.15 %	4501
149	-9.679398557	3.55 %	3104
70	-2.262780263	3.52 %	3073
16	-1.428433325	2.50 %	2181
57	-1.147033858	2.34 %	2048
339	-1.860240067	2.19 %	1913



Analyses in Vannfly

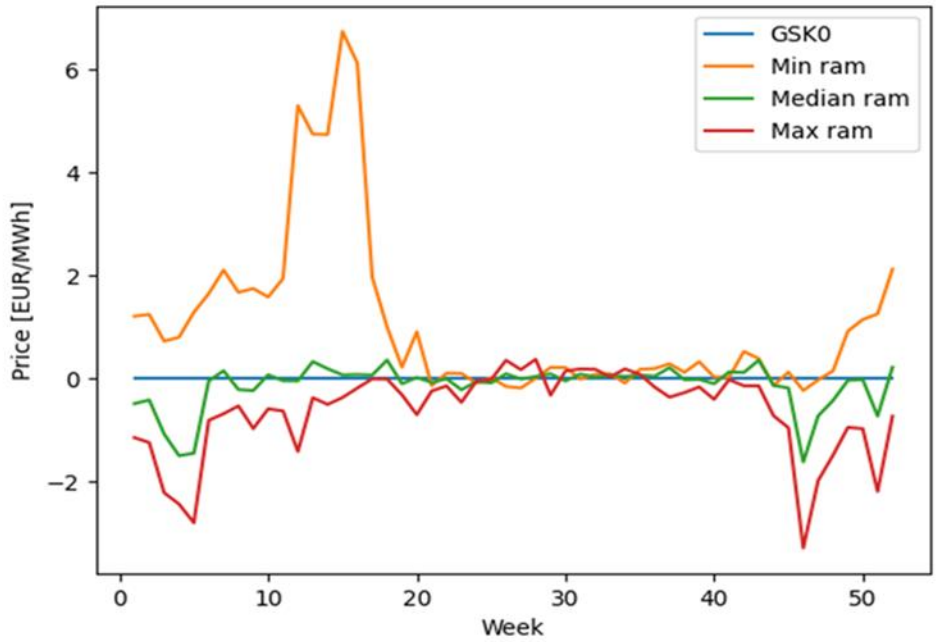
Teknologi for et bedre samfunn

Research question 1

«How different will the results be when using exogenous constraints based on a detailed grid description, instead of using the detailed grid description itself»

Findings research question 1

- Detailed grid description not publically available
- Exogenous constraints can give similar results as a detailed grid
  - Relaxing/tightening the constraints can show the sensitivities
  - Practical to use a GSK which gives unchanging PTDFs, so that only RAM is varying.
    - 1 varying variable per line instead of 12

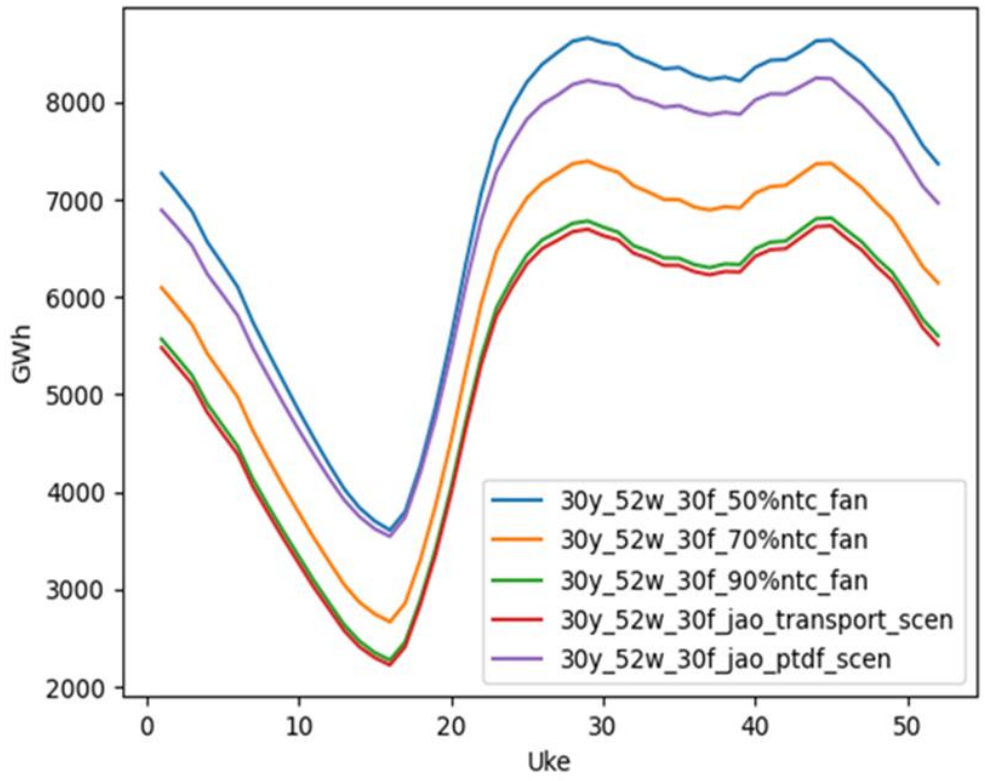


Research question 2

«What will be the effect of using different grid restrictions in the strategy problem than in the simulation problem»

Findings research question 2

- Scaling NTC-values makes most of the difference between using NTC and PTDF go away
- But still:
  - Some amount of rationing in all cases with NTC-constraints
  - Quite big differences in reservoir handling in some areas



Conclusions

- For Statnett/Nordic TSOs:
  - Both PTDFs and RAM can vary with time. We recommend keeping PTDFs constant and deal with variations in RAM
  - Therefore: Choose a ‘robust’ GSK which is indpendent of the market situation for long-term capacities, so that PTDFs are kept constant
  - Publish the same constraints for a range of different market situations to show the likely RAM values
- For producers:
  - We recommend using flow-based constraints if possible (both in strategy and simulation problem)
  - If using transport constraints: Be aware of the scaling of the capacities and do sensitivity analyses

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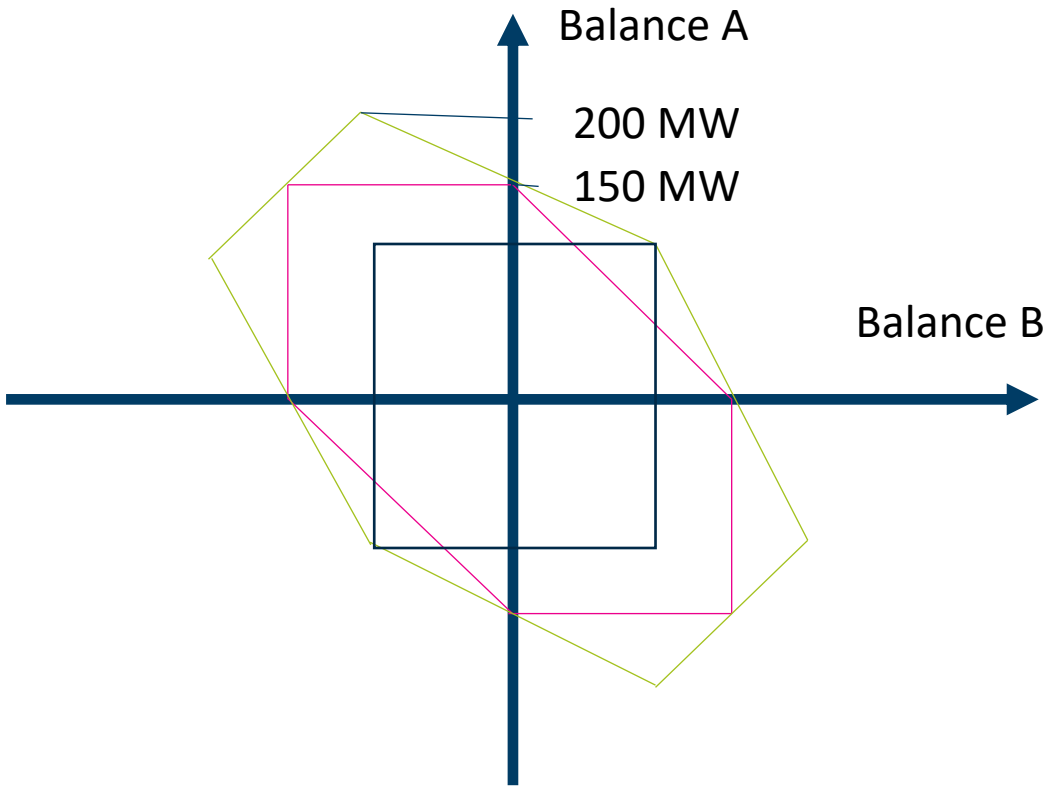
Teknologi for et bedre samfunn

Available domain



NTC Domain 1

NTC Domain 2

FB Domain

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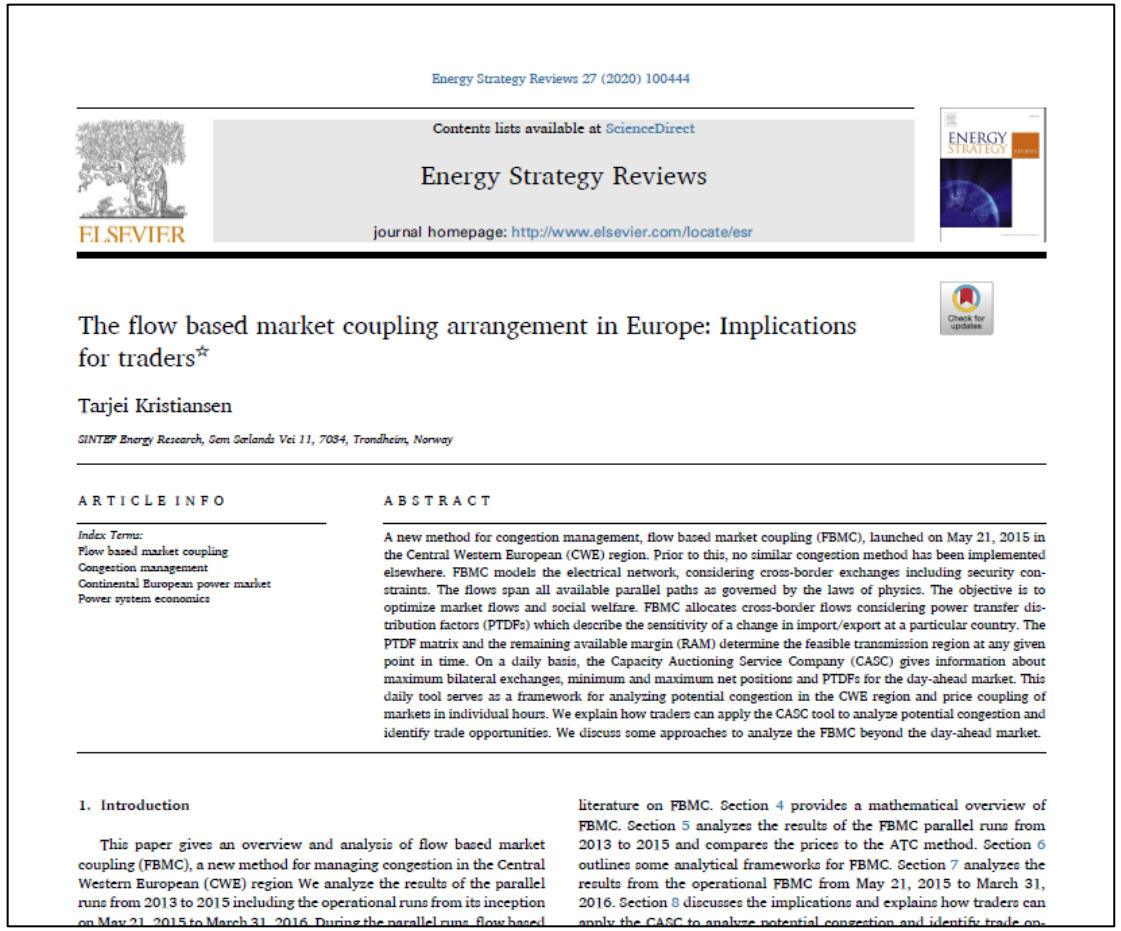
Features of FBMC

- The area price consists of the components:
  1) energy, 2) congestion, 3) losses
- Allows for price differences between uncongested areas - increases the ability of the market to utilize all available capacity
- The market clearing solves both net positions and flows and thus scheduled and physical flows are converging

Further reading: "Methodology and concepts for the Nordic Flow-Based Market Coupling Approach".



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journal homepage: http://www.elsevier.com/locate/esr

The flow based market coupling arrangement in Europe: Implications for traders☆

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ARTICLE INFO

Index Terms:
Flow based market coupling
Congestion management
Continental European power market
Power system economics

ABSTRACT

A new method for congestion management, flow based market coupling (FBMC), launched on May 21, 2015 in the Central Western European (CWE) region. Prior to this, no similar congestion method has been implemented elsewhere. FBMC models the electrical network, considering cross-border exchanges including security constraints. The flows span all available parallel paths as governed by the laws of physics. The objective is to optimize market flows and social welfare. FBMC allocates cross-border flows considering power transfer distribution factors (PTDFs) which describe the sensitivity of a change in import/export at a particular country. The PTDF matrix and the remaining available margin (RAM) determine the feasible transmission region at any given point in time. On a daily basis, the Capacity Auctioning Service Company (CASC) gives information about maximum bilateral exchanges, minimum and maximum net positions and PTDFs for the day-ahead market. This daily tool serves as a framework for analyzing potential congestion in the CWE region and price coupling of markets in individual hours. We explain how traders can apply the CASC tool to analyze potential congestion and identify trade opportunities. We discuss some approaches to analyze the FBMC beyond the day-ahead market.

1. Introduction

This paper gives an overview and analysis of flow based market coupling (FBMC), a new method for managing congestion in the Central Western European (CWE) region We analyze the results of the parallel runs from 2013 to 2015 including the operational runs from its inception on May 21, 2015 to March 31, 2016. During the parallel runs, flow based

literature on FBMC. Section 4 provides a mathematical overview of FBMC. Section 5 analyzes the results of the FBMC parallel runs from 2013 to 2015 and compares the prices to the ATC method. Section 6 outlines some analytical frameworks for FBMC. Section 7 analyzes the results from the operational FBMC from May 21, 2015 to March 31, 2016. Section 8 discusses the implications and explains how traders can apply the CASC to analyze potential congestion and identify trade op-

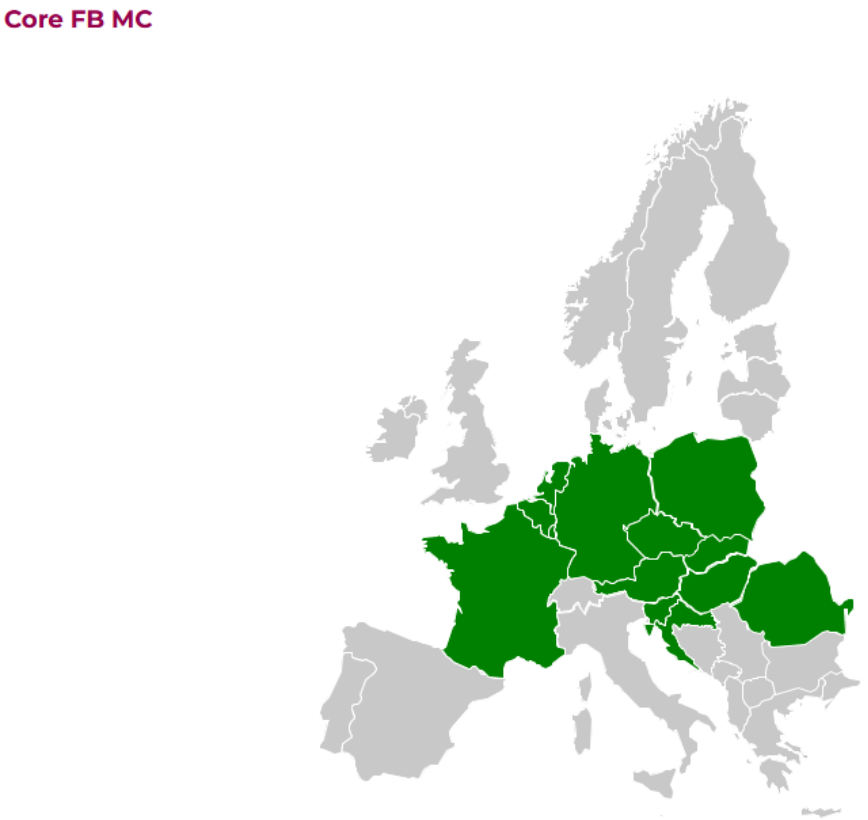
Flow-based market clearing in Europe

Teknologi for et bedre samfunn

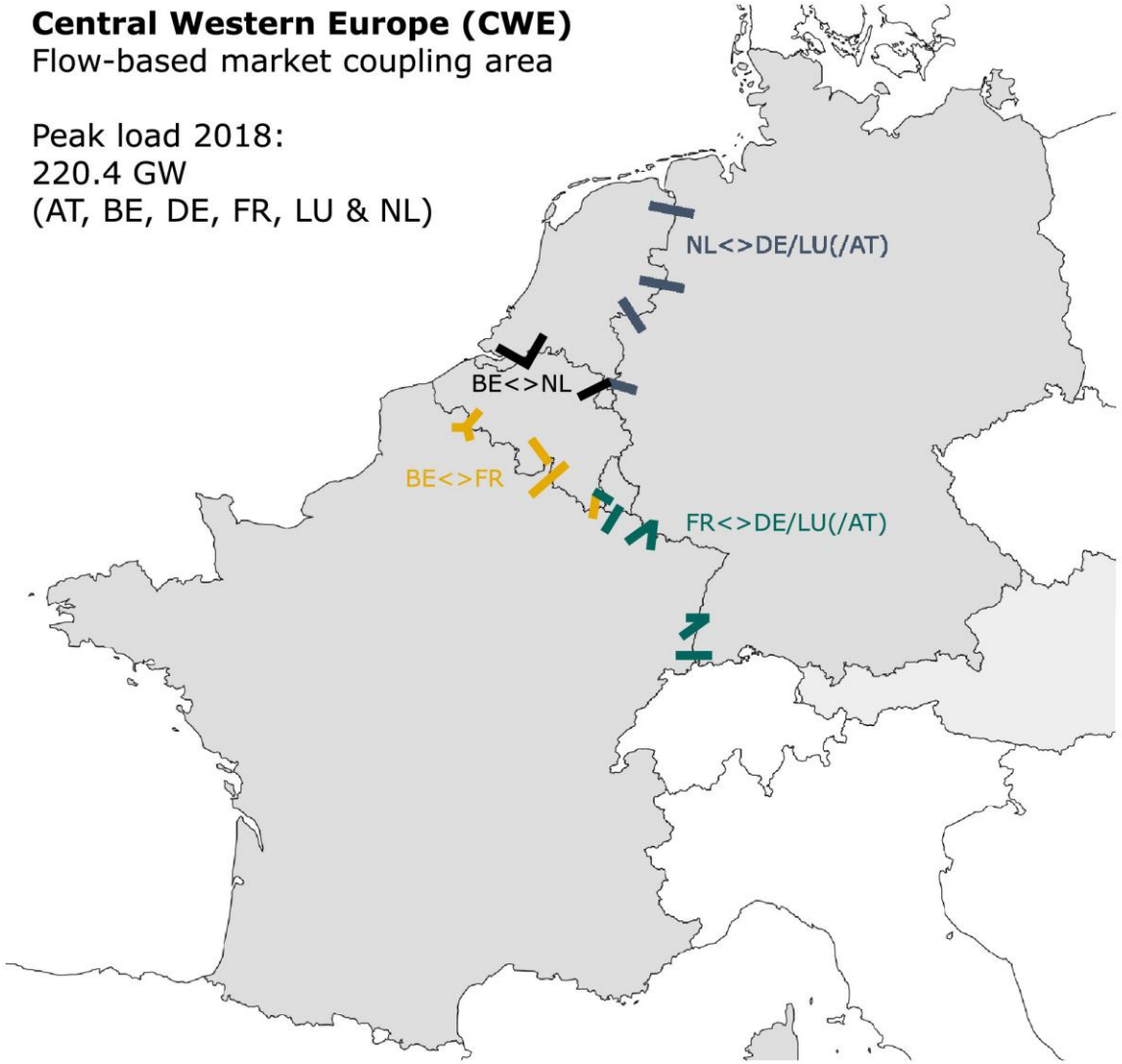
Development

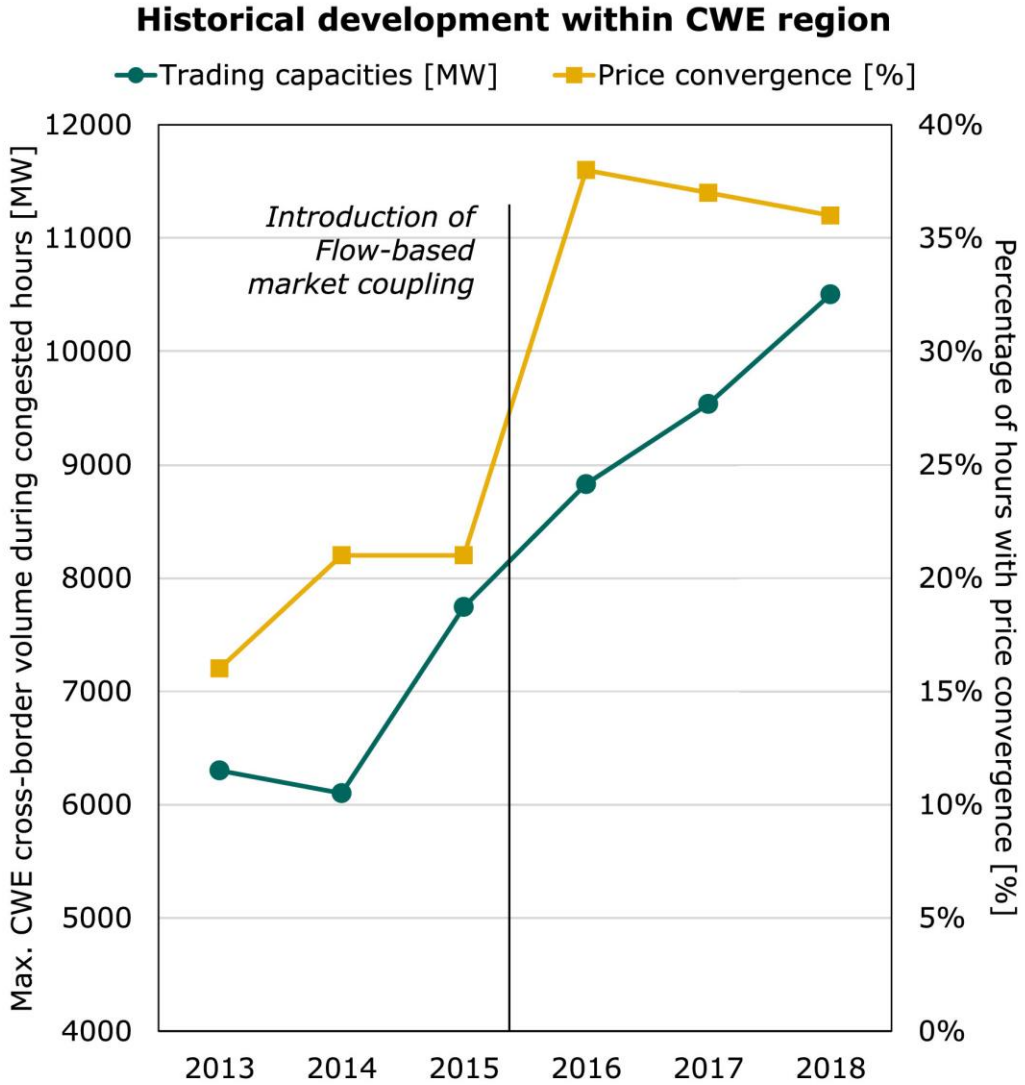
- Flow-Based capacity calculation method is required by the Commission Regulation 2015/1222 establishing a guideline on capacity allocation and congestion management (Article 20)

- CWE FB MC go-live 20/05-2015
- Core FB MC go-live 08/06-2022



Core Flow-Based Market Coupling (Core FB MC)





Source: Schönheit, D., et al. "Toward a fundamental understanding of flow-based market coupling for cross-border electricity trading." Advances in Applied Energy

Experiences from FBMC in CWE

Tarjei Kristiansen, The flow-based market coupling arrangement in Europe: Implications for traders, Energy Strategy Reviews, 2020

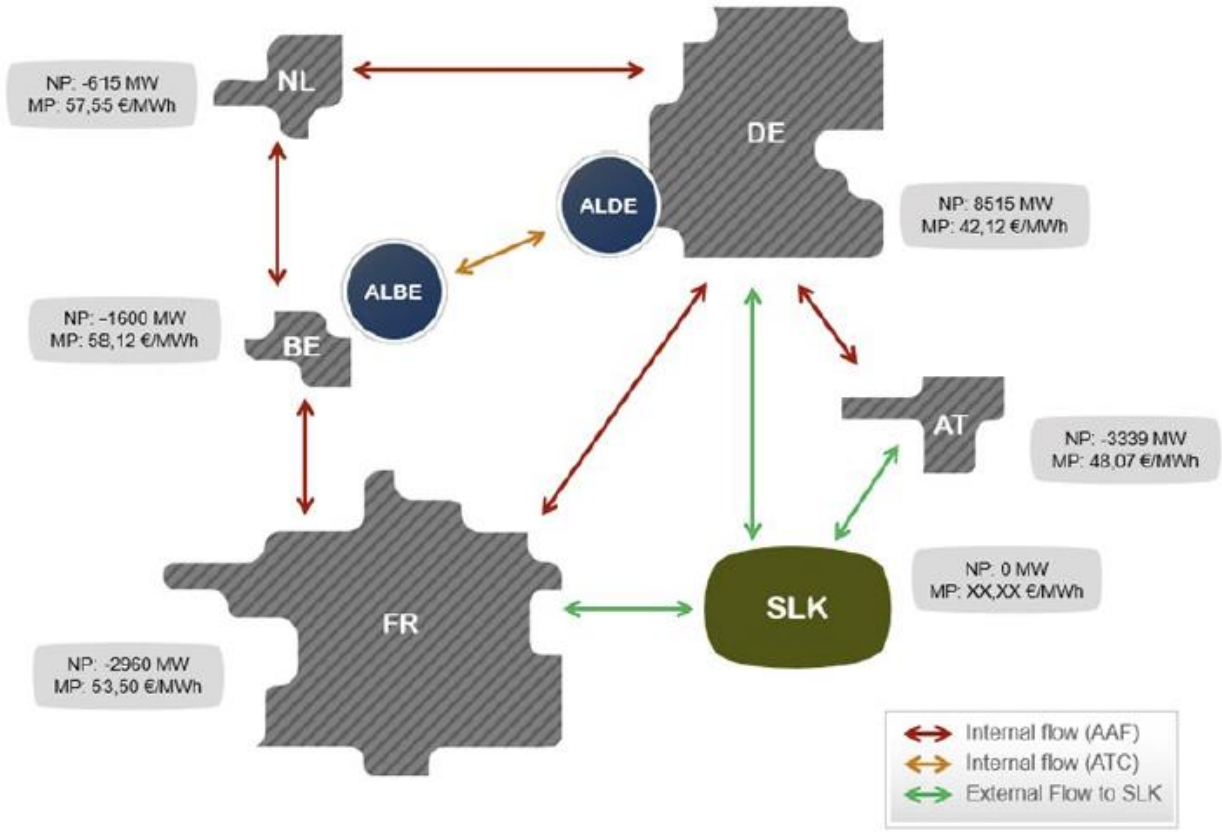
- Parallel run results and operational results from the flow-based market coupling between 2013 and 2015 in CWE were analyzed.
- Cross-border country price differentials decreased as exports and imports rose because of increased cross-border capacity.
- FBMC leads to higher social welfare and cross-border flows than NTC, but more demanding to use
- If TSOs continue to only publish forecasts of power transfer distribution factors for the day-ahead market, traders will find it difficult to forecast prices beyond this timeframe.

		Average cross-border price spread
ATC	BE-NL	1.91
	DE-NL	11.03
	FR-BE	4.62
	DE-FR	4.49
FBMC	BE-NL	2.59
	DE-NL	7.51
	FR-BE	2.29
	DE-FR	2.63
Delta	BE-NL	0.68
	DE-NL	-3.52
	FR-BE	-2.33
	DE-FR	-1.86

FB methods and market patches

- Flow Based Intuitive vs
  Flow Based Plain
  - CWE switches to FBP
  - 18kEUR saving per day for MRC region

- Evolved Flow-based method
  - Maximisation social welfare
  - Can lead to non-intuitive flow



SINTEF

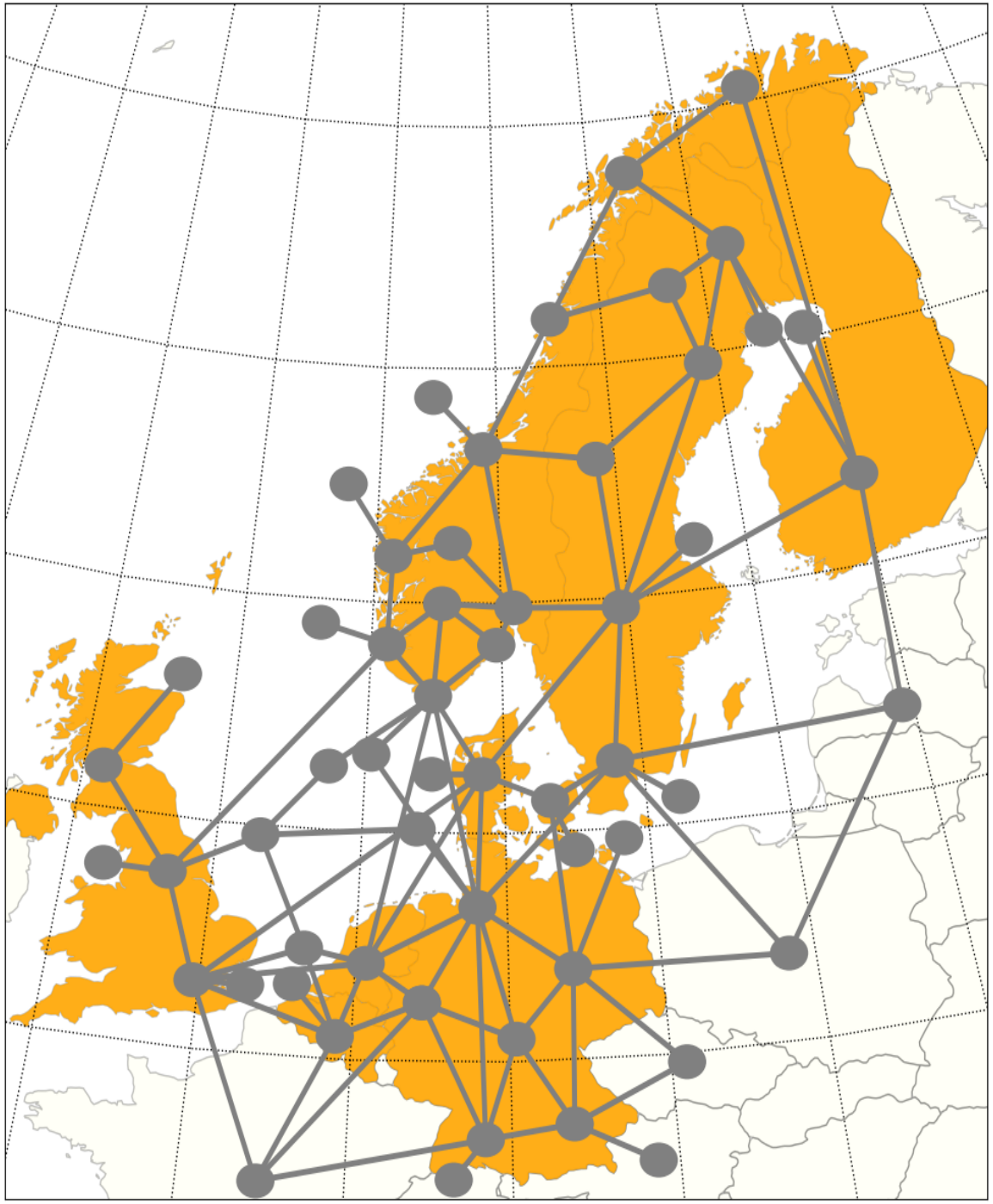
Analyser – Noen resultater fra EMPS med FBMC

Teknologi for et bedre samfunn

Oversikt

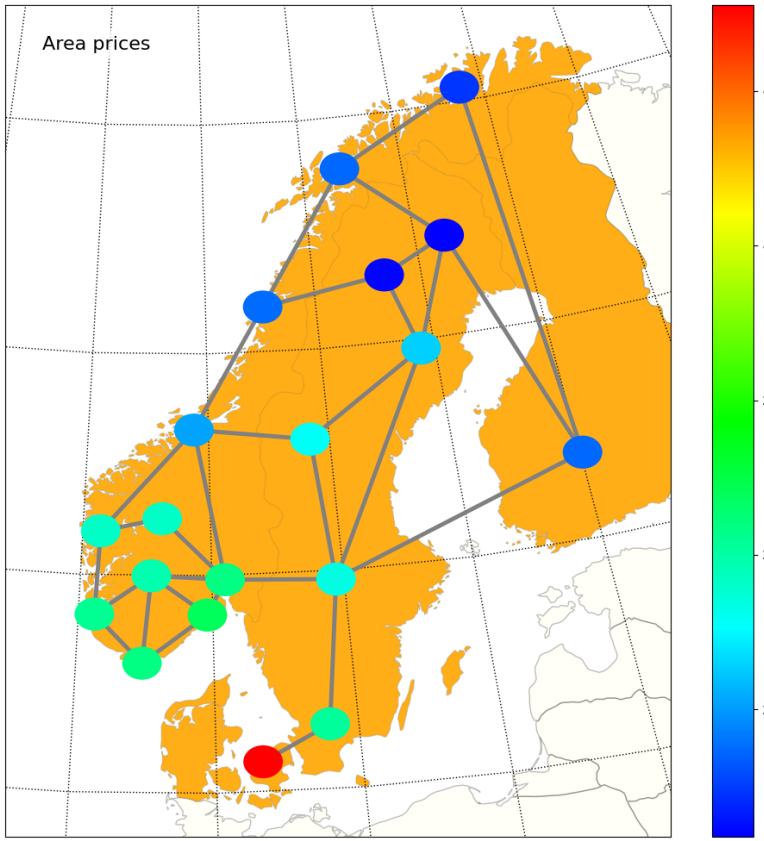
- 57 områder
  (19 AC områder)
- 30 år tilsig vind og solserier
- 3 timers oppløsning

- Simulasjon per simulert år
  ca. 1.5 – 2 min (samtap_cplex)

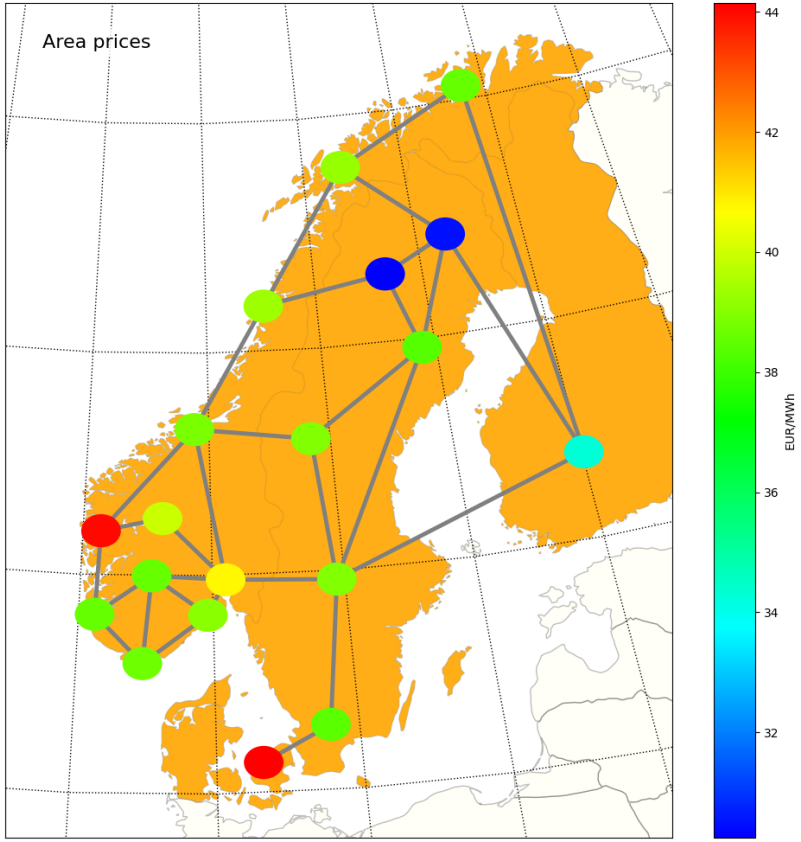


Områdepriser

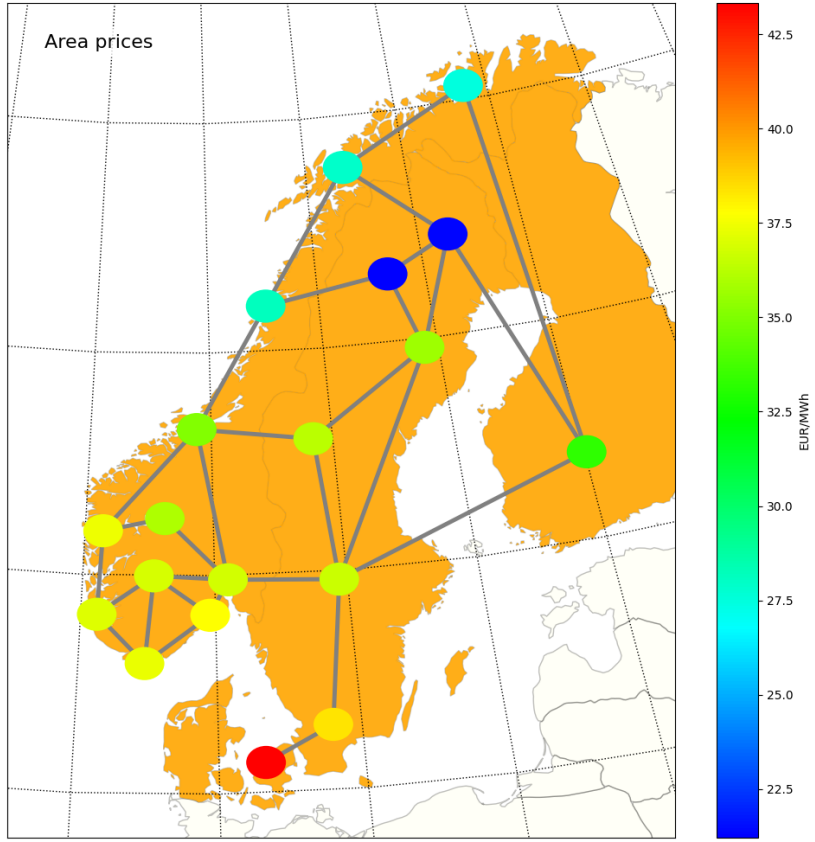
Kun NTC



FBMC – RAM basert på NTC



FBMC – alle CNE i Norden



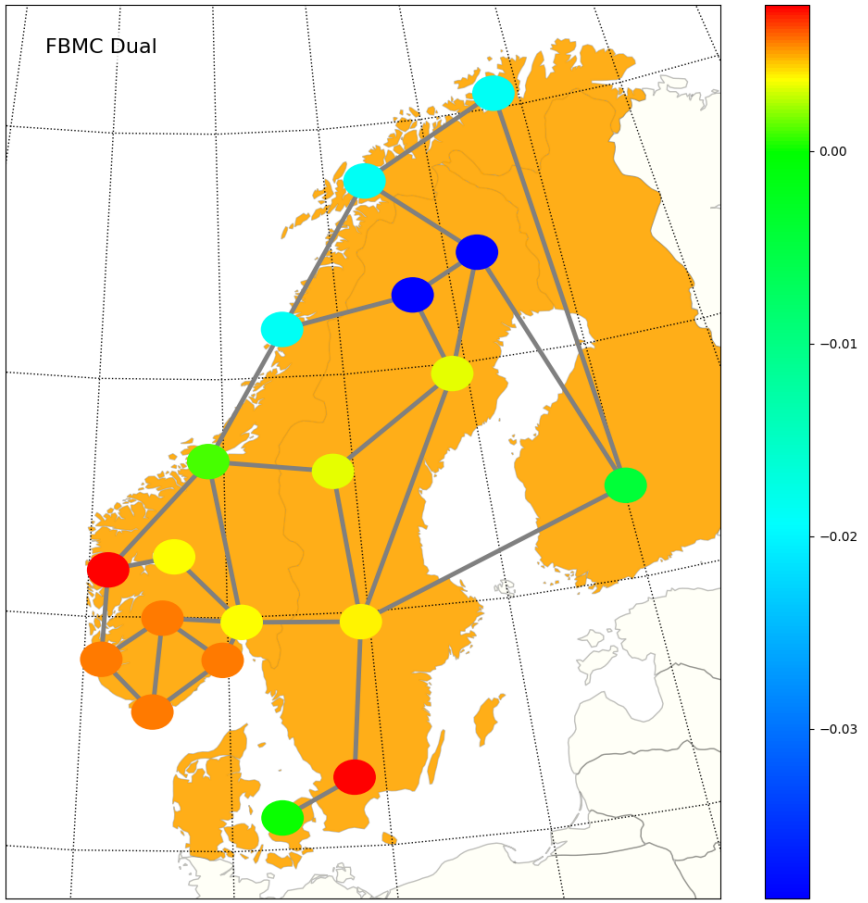
Priseffekt over CNE i EMPS

Priseffekt:

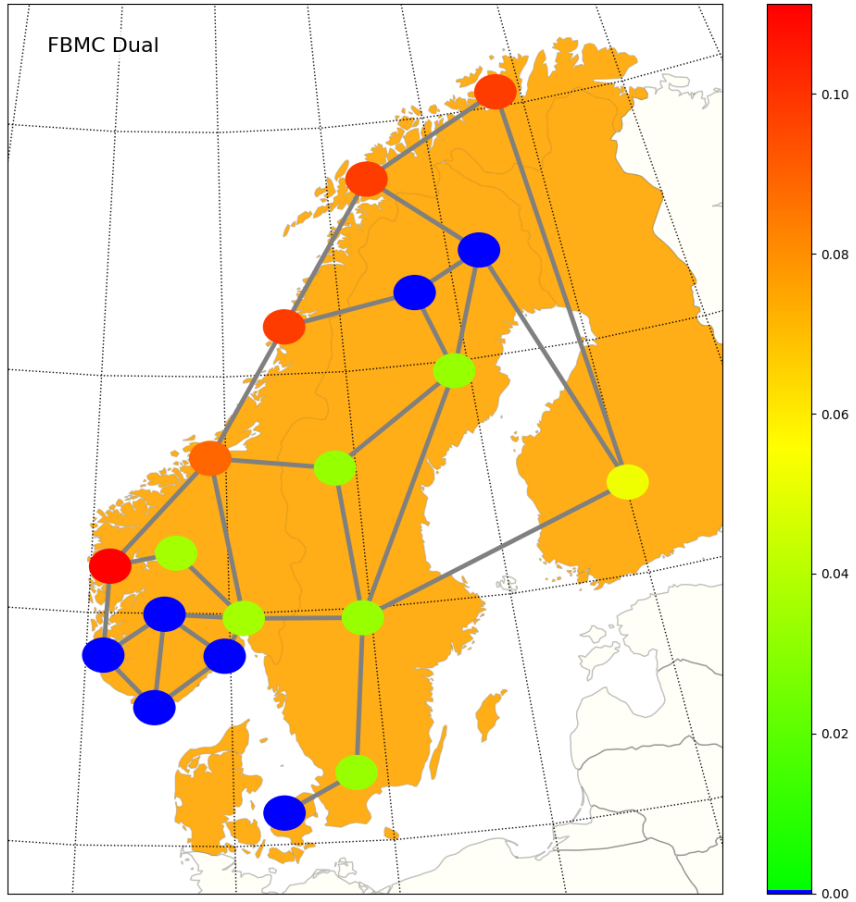
- $\sum(\lambda_{CNE} * PTDF_{CNE})$

- Konsekvens av flytbegrensing på CNE på områdepris

Gjennomsnitt

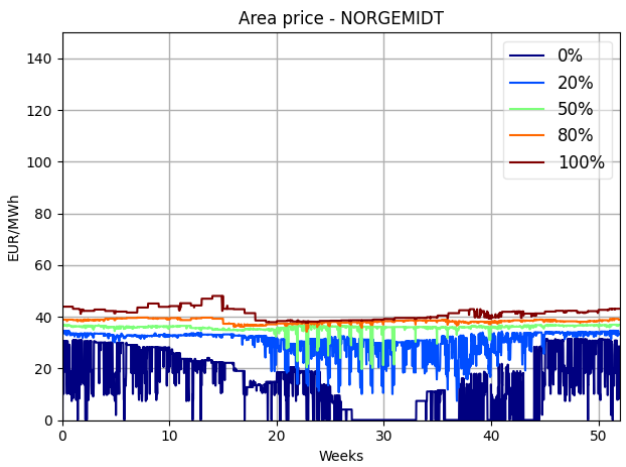


Utvalgt time

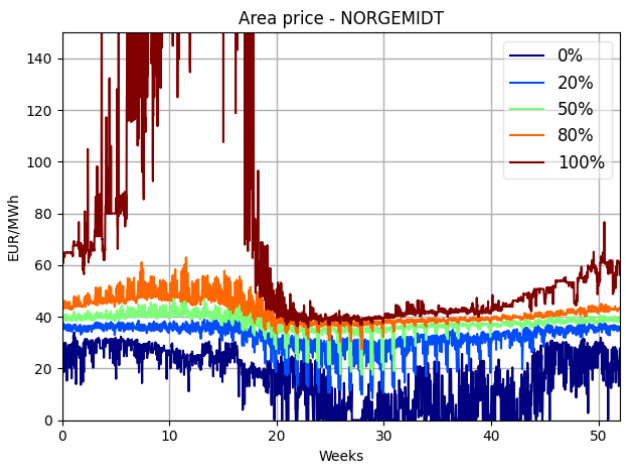


Prices NO3 from simulations

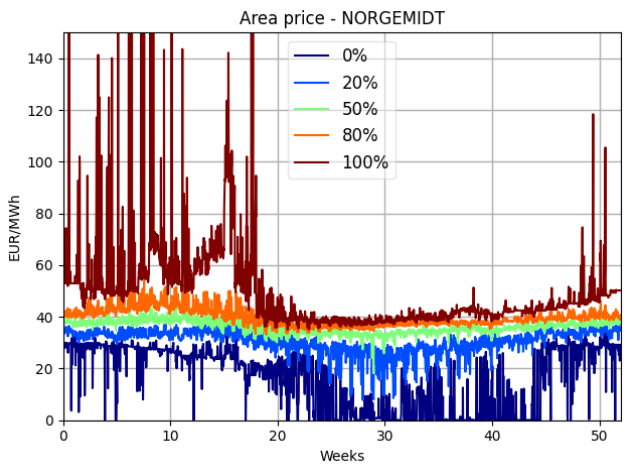
Kun NTC



FBMC – RAM basert på NTC



FBMC – alle CNE i Norden

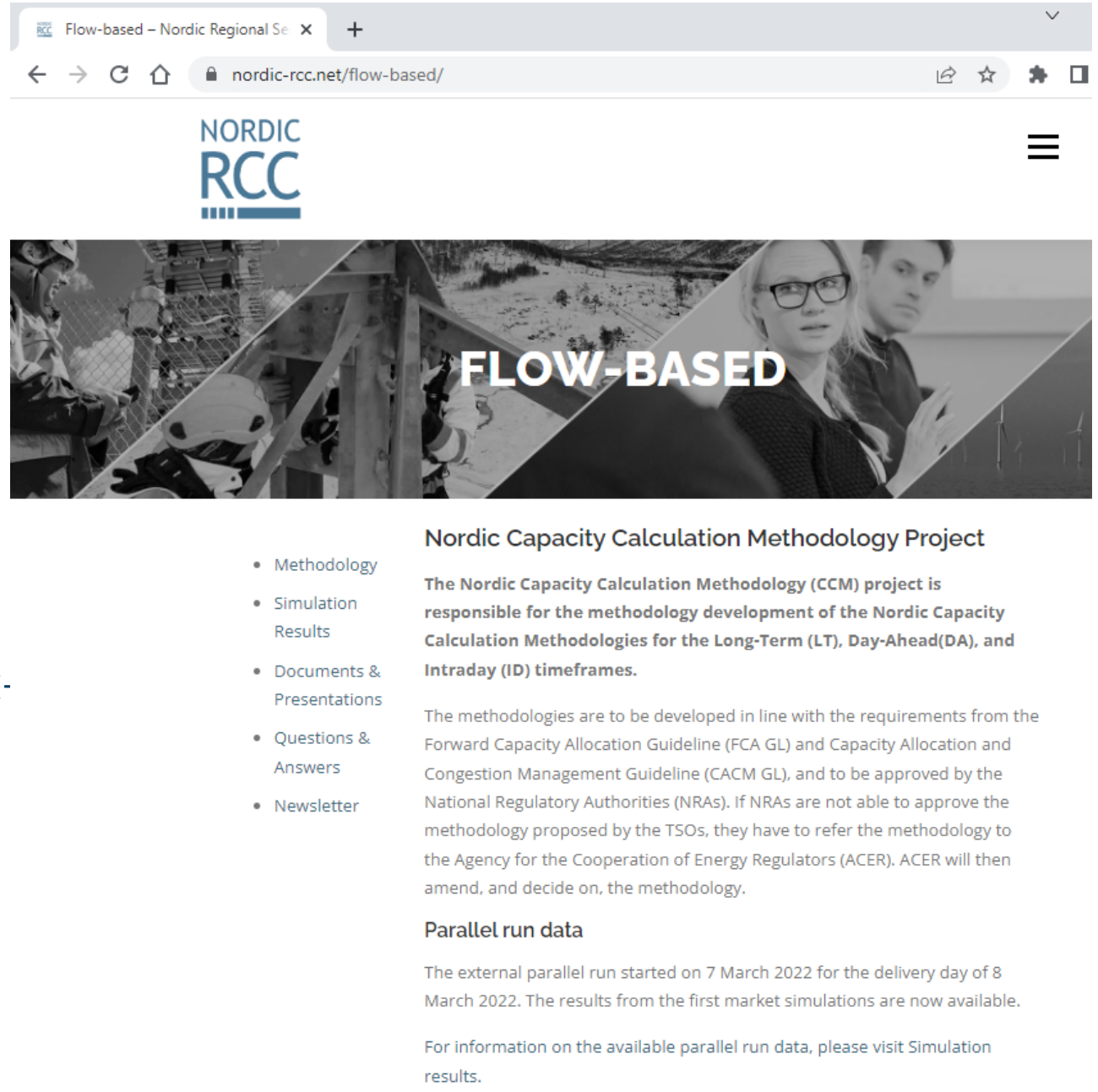


NORDIC CCM og Parallelkjøring

Teknologi for et bedre samfunn

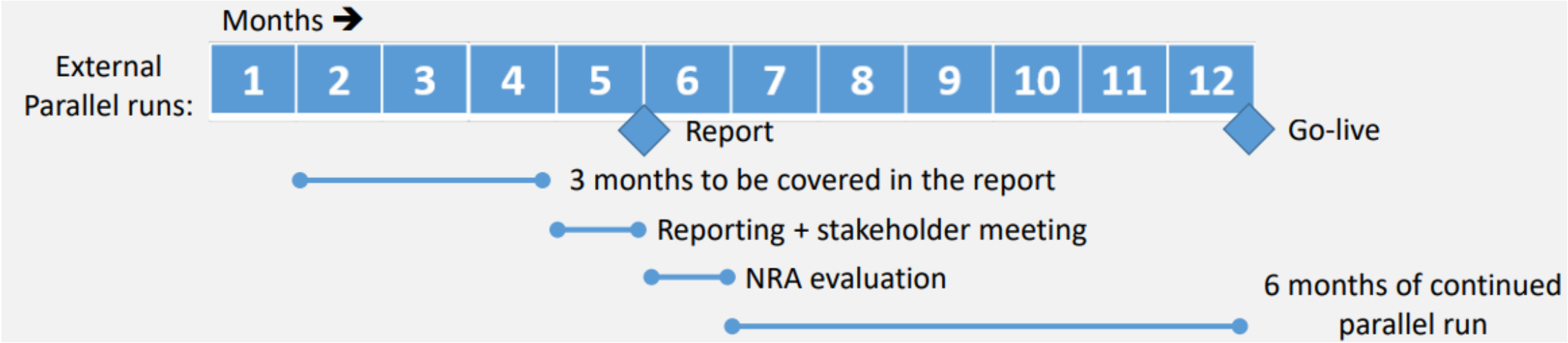
Nordic CCM

- Ansvarlig å utvikle metode for kapasitetsberegning i Norden
  - Long-Term
  - Day-Ahead
  - Intraday
- Metodologi må være i henhold til nett-kodene CACM og FCA
- Må bli godkjent av reguleringsmyndighetene
- https://nordic-rcc.net/flow-based/



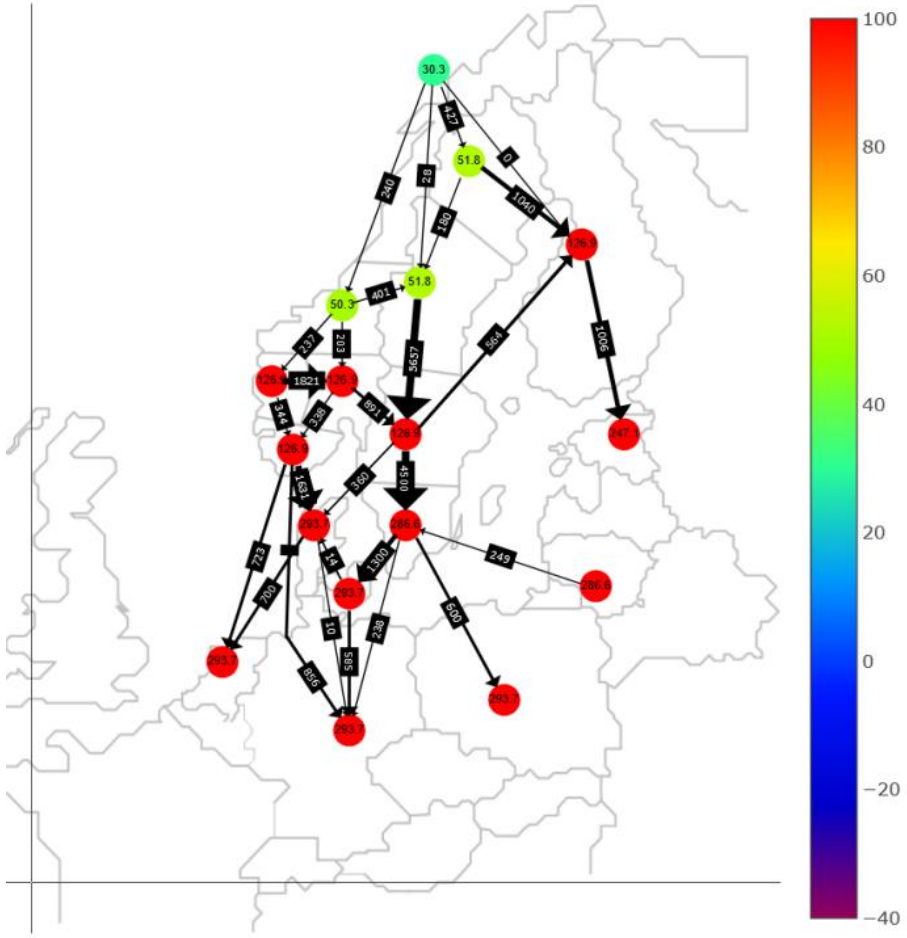
Tidslinje før go-live

- Start eksterne parallellkjøringer 7. mars 2022 -> Go-live tidligst mars 2023

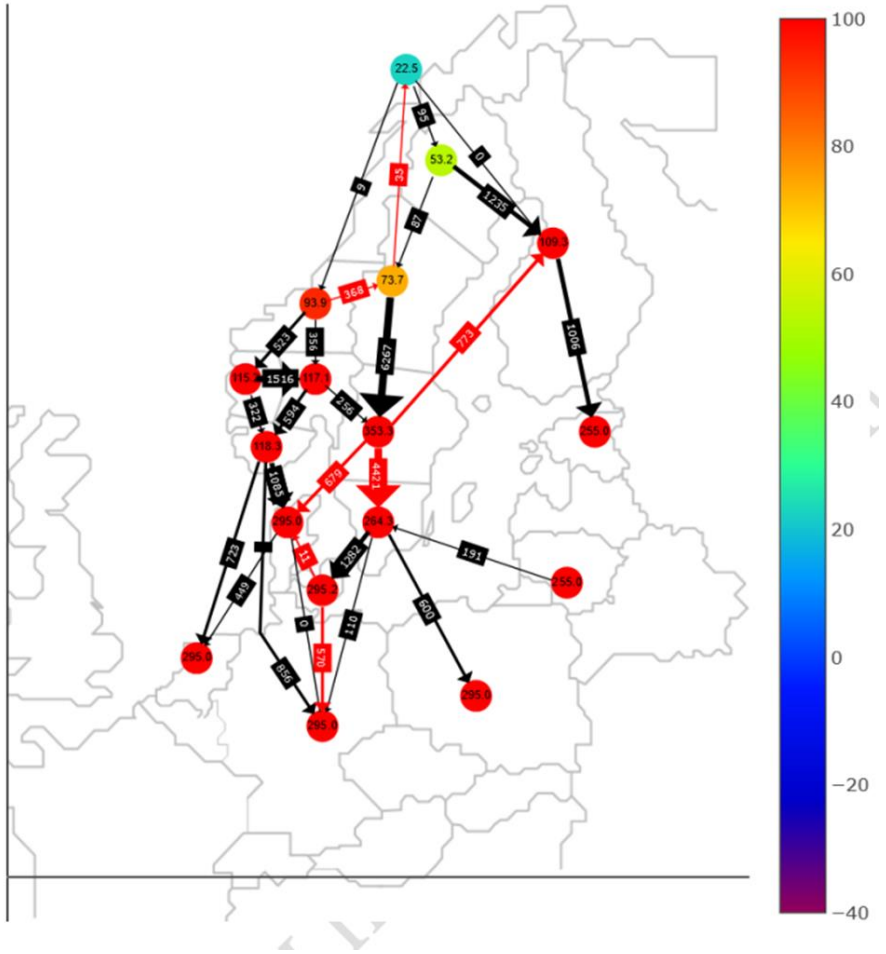


Eksempel på forskjell NTC og FBMC fra parallellkjøring

NTC 2021-10-08 08:00

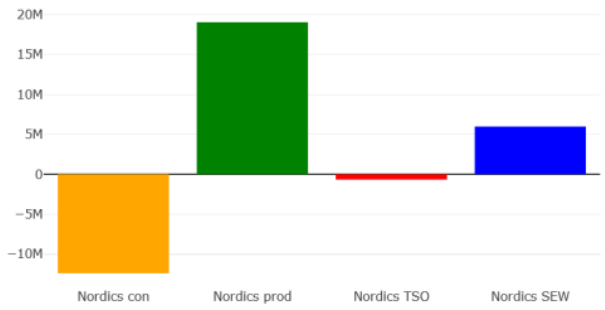


FB 2021-10-08 08:00

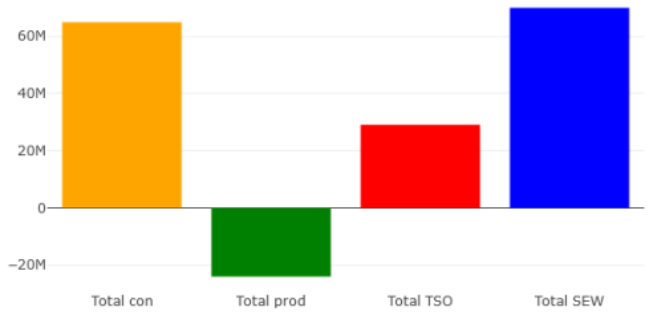


Samfunnsøkonomi – Fordeling aktører

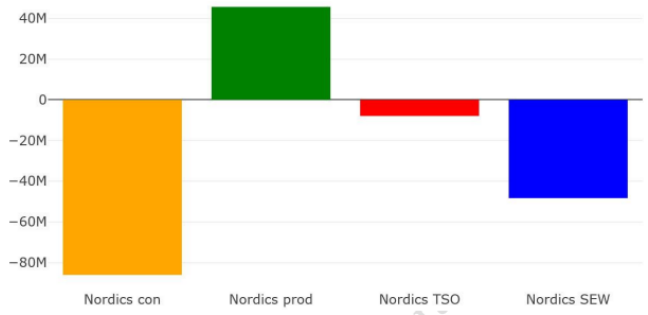
Uke 35-36



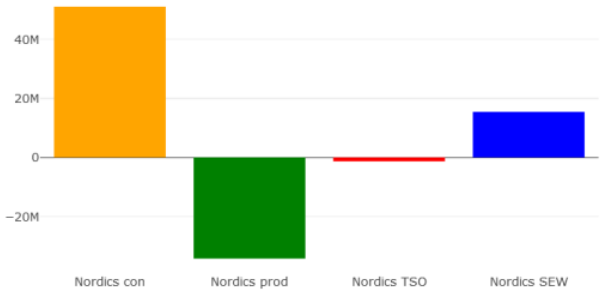
Uke 40-43



Uke 49-50

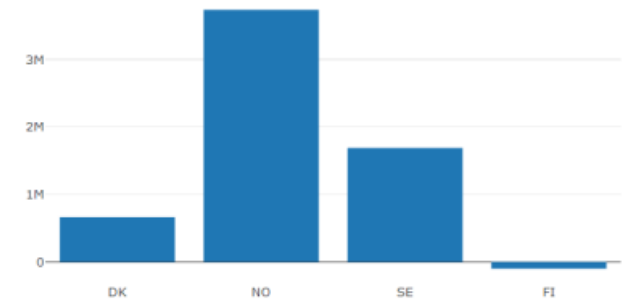


Uke 51-52

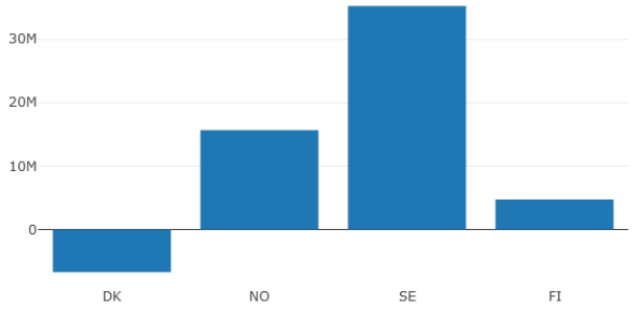


Samfunnsøkonomi – Fordeling land

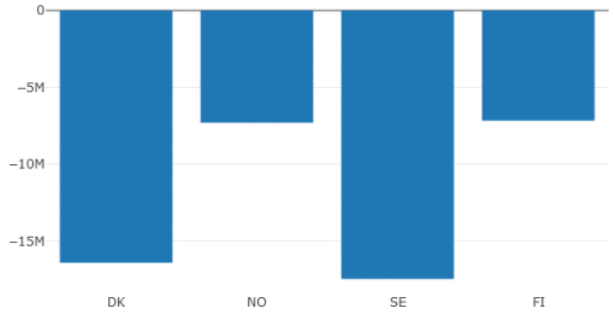
Uke 35-36



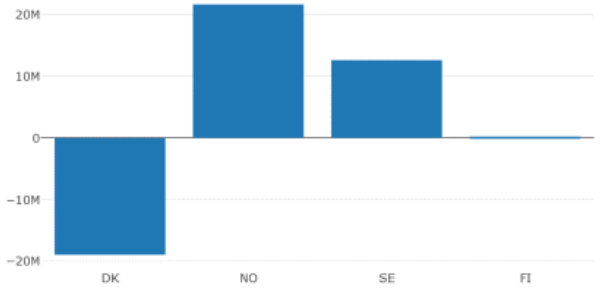
Uke 40-43



Uke 49-50

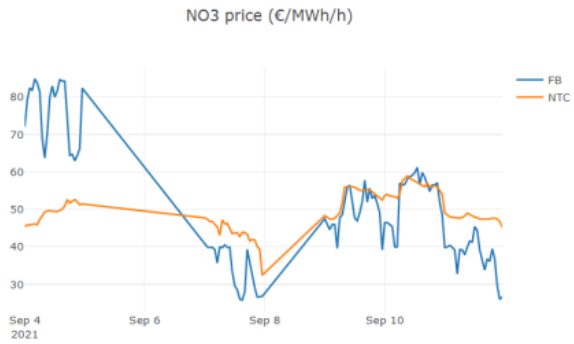


Uke 51-52

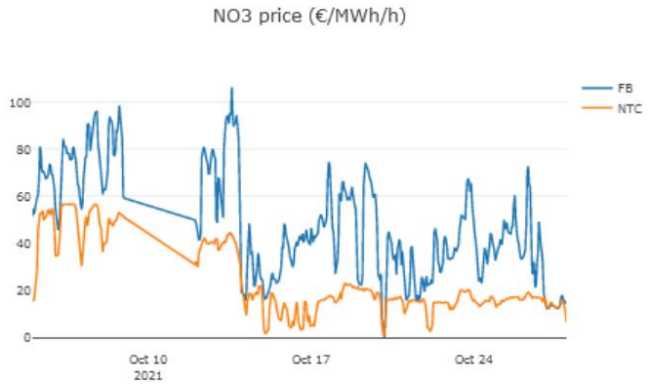


Priser NO3

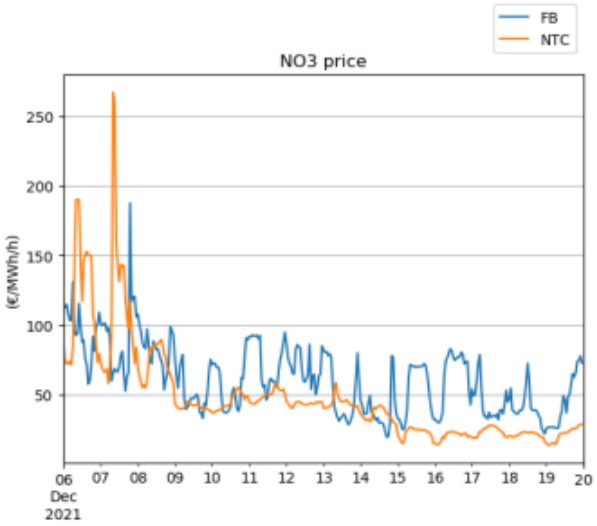
Uke 35-36



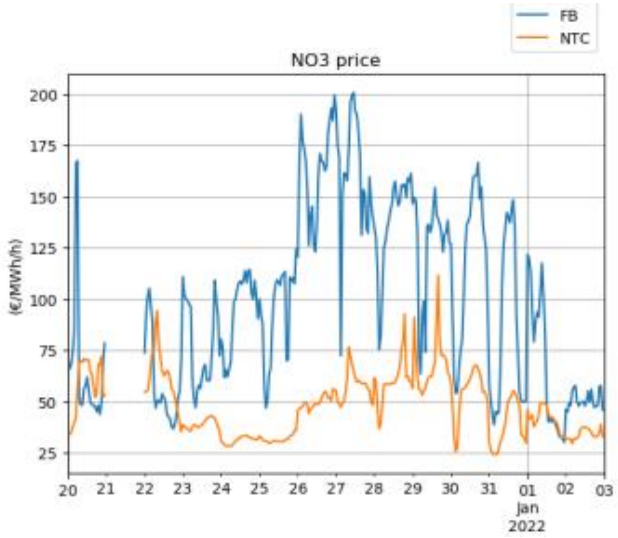
Uke 40-43



Uke 49-50

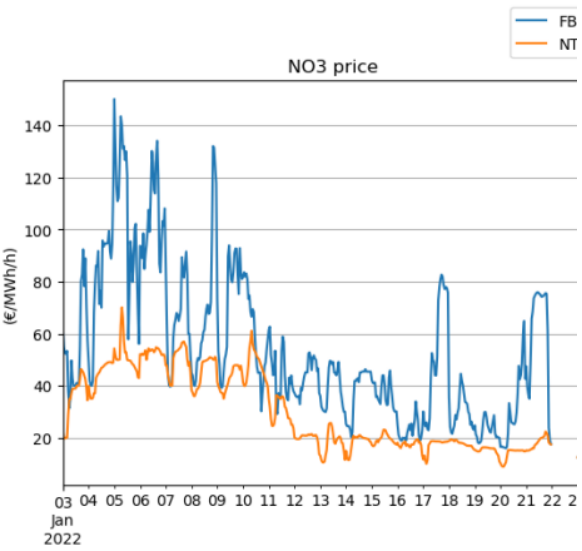


Uke 51-52

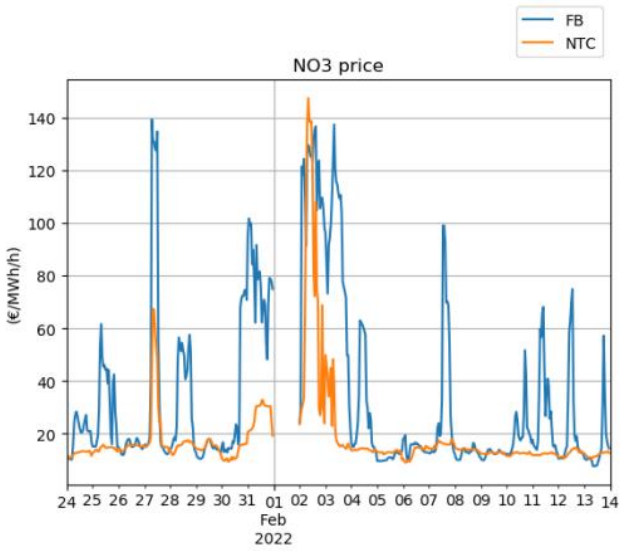


Priser NO3

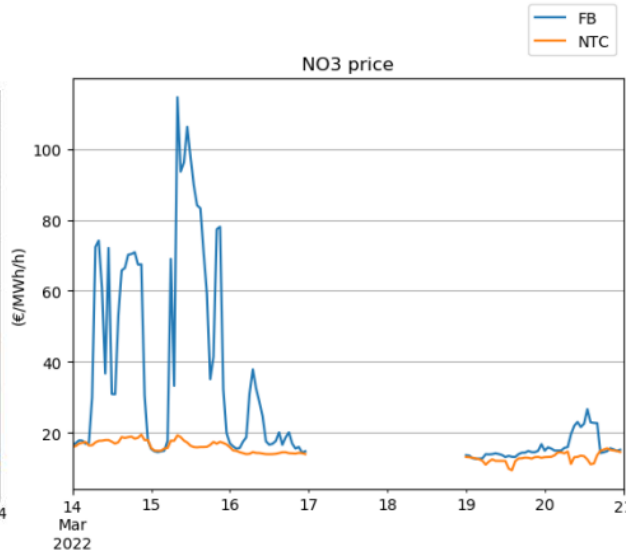
Uke 1-3



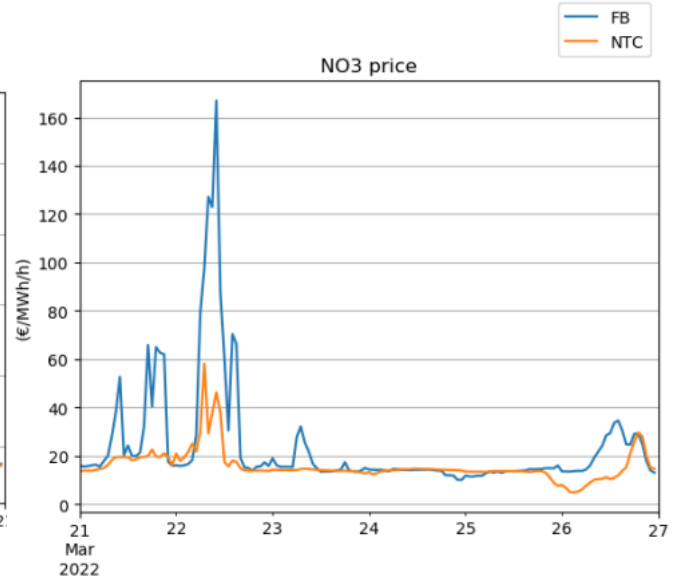
Uke 4-6



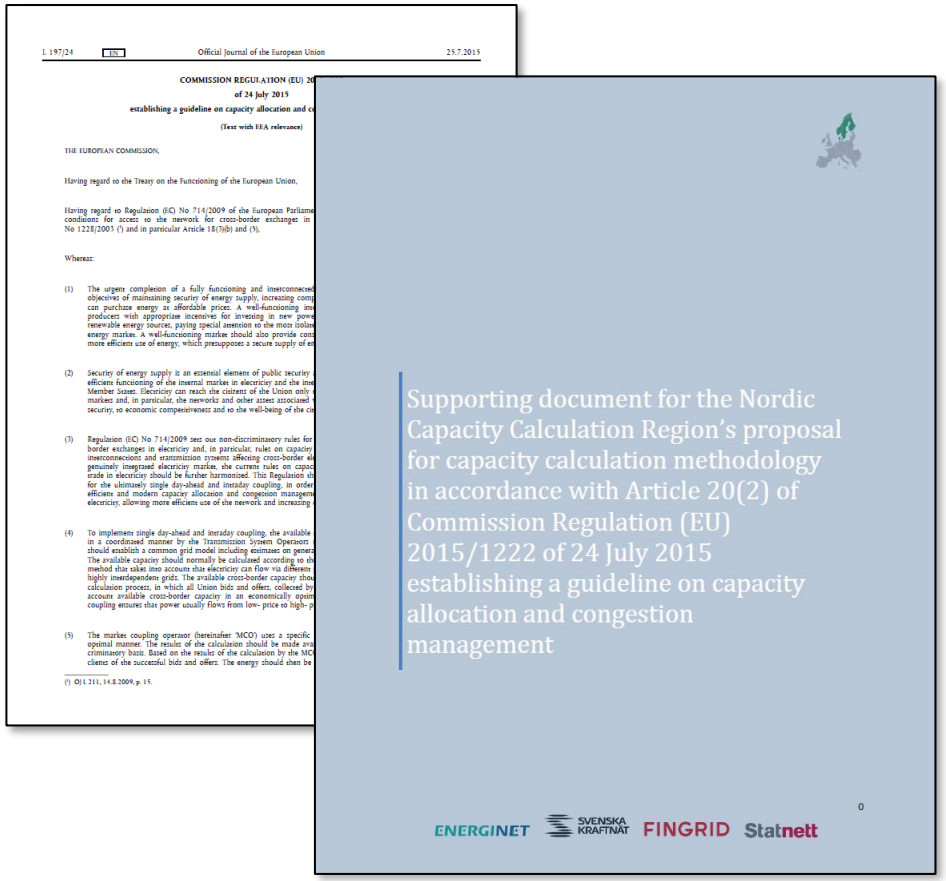
Uke 11



Uke 12



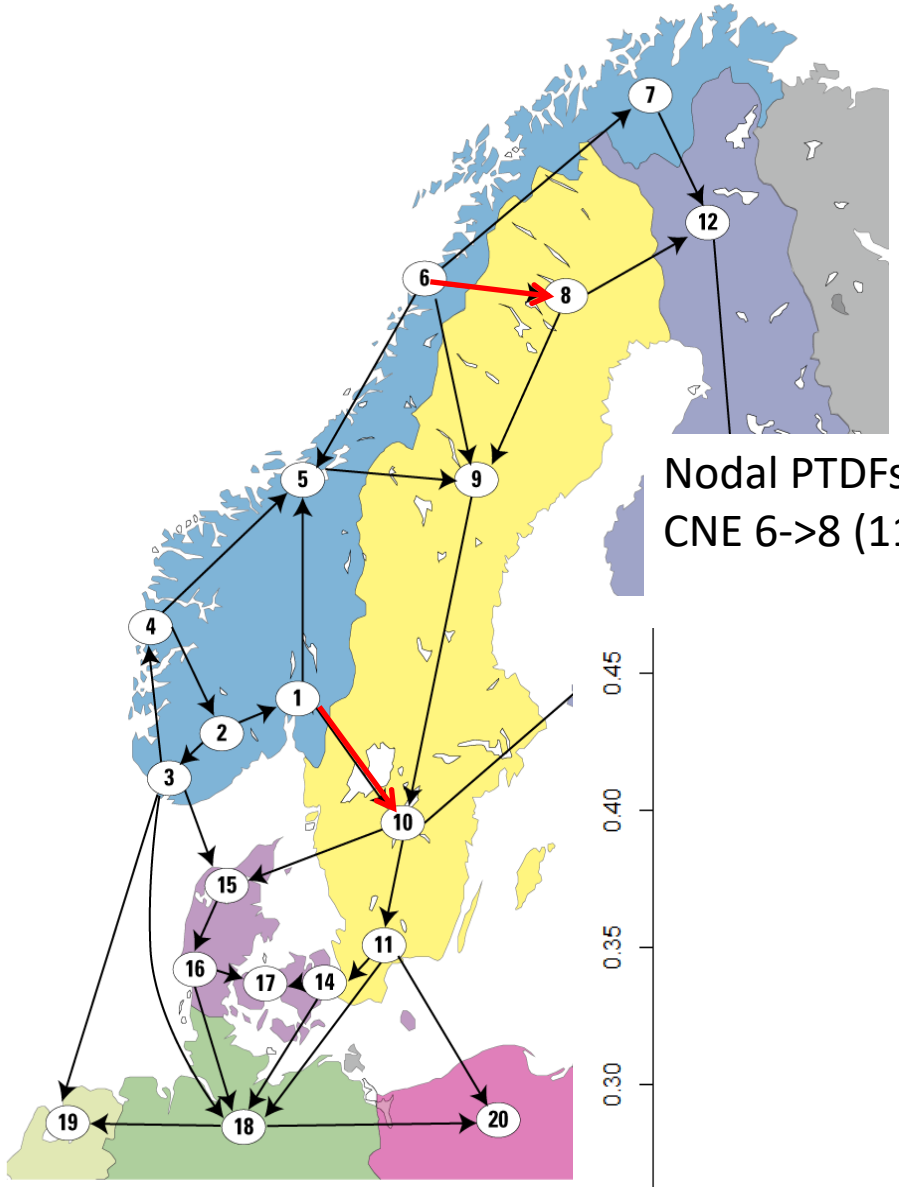
Network Code on Capacity Allocation and Congestion Management (NC CACM)



(4) […] The available capacity should normally be calculated according to the so-called flow-based calculation method, a method that takes into account that electricity can flow via different paths and optimises the available capacity in highly interdependent grids. […]

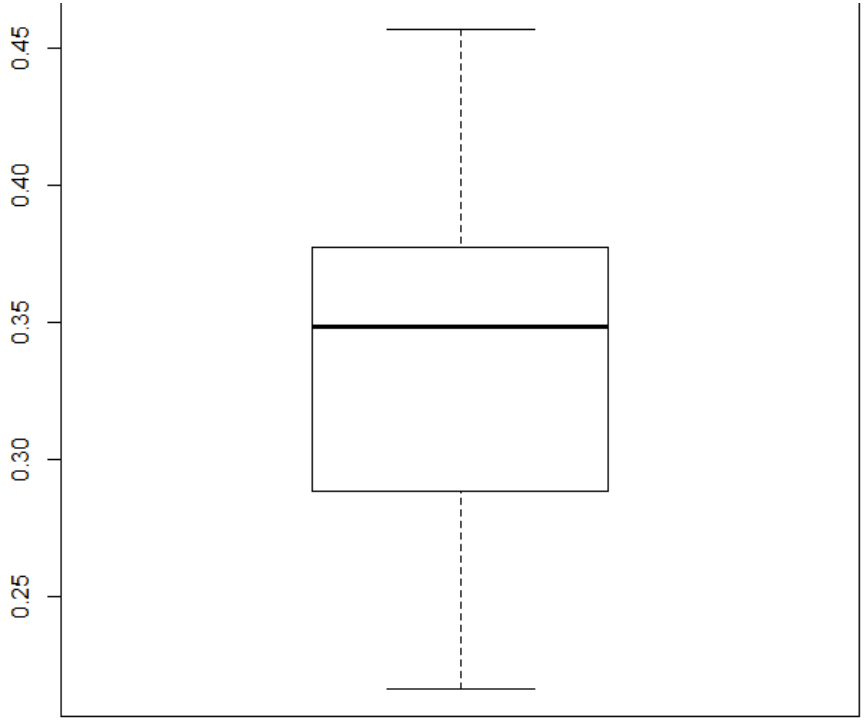
(7) There are two permissible approaches when calculating cross-zonal capacity: flow-based or based on coordinated net transmission capacity. The flow-based approach should be used as a primary approach for day-ahead and intraday capacity calculation where cross-zonal capacity between bidding zones is highly interdependent. The flow-based approach should only be introduced after market participants have been consulted and given sufficient preparation time to allow for a smooth transition. The coordinated net transmission capacity approach should only be applied in regions where cross-zonal capacity is less interdependent and it can be shown that the flow-based approach would not bring added value.

Example: Distribution of Nodal PTDFs

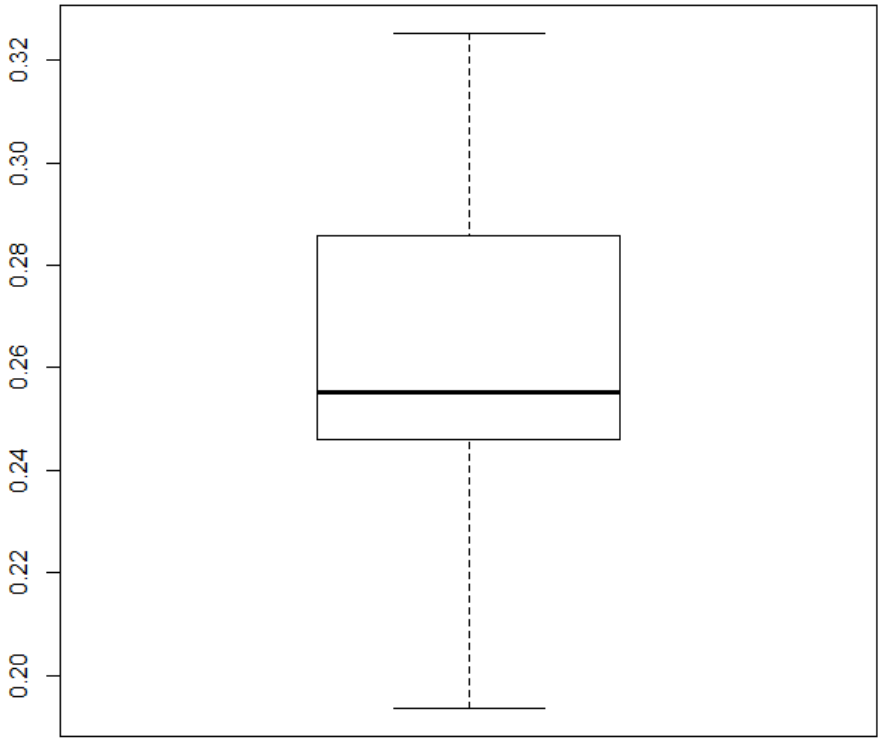


NB! Data fra NVE. Områdeinndeling i datasett er noe forskjellig fra figur.

Nodal PTDFs from nodes in area 6 on CNE 6->8 (114 nodes)



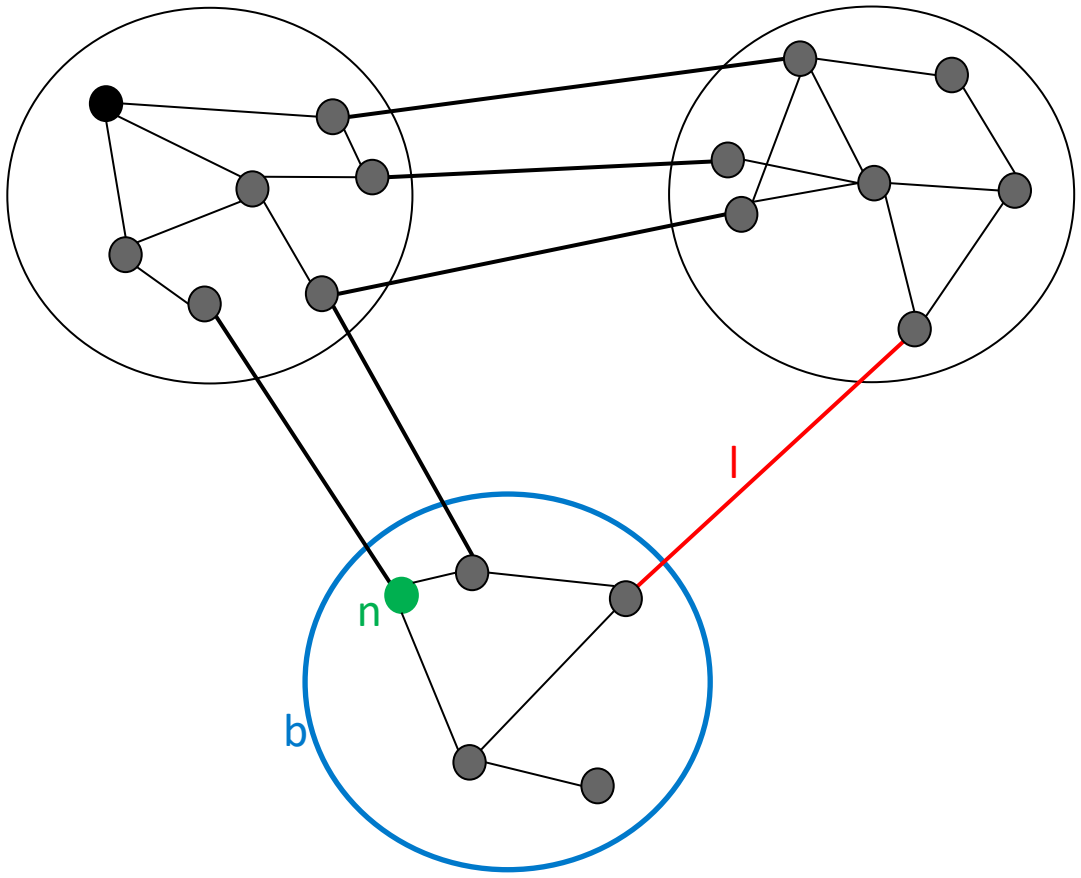
Nodal PTDFs from nodes in area 5 on CNE 1->10 (125 nodes)



Intro til Flow-based market clearing

- Net Transfer Capacity vs. Flow-based market clearing
- Available domain to the market
- Power transfer distribution factors
- From nodal to zonal representation

The Flow-Based Constraint



b – bidding zone
n – node
l – critical network element

A critical network element (**CNE**) is a network element that the TSO requires to monitor for potential overloads.

FB constraint for each CNE:

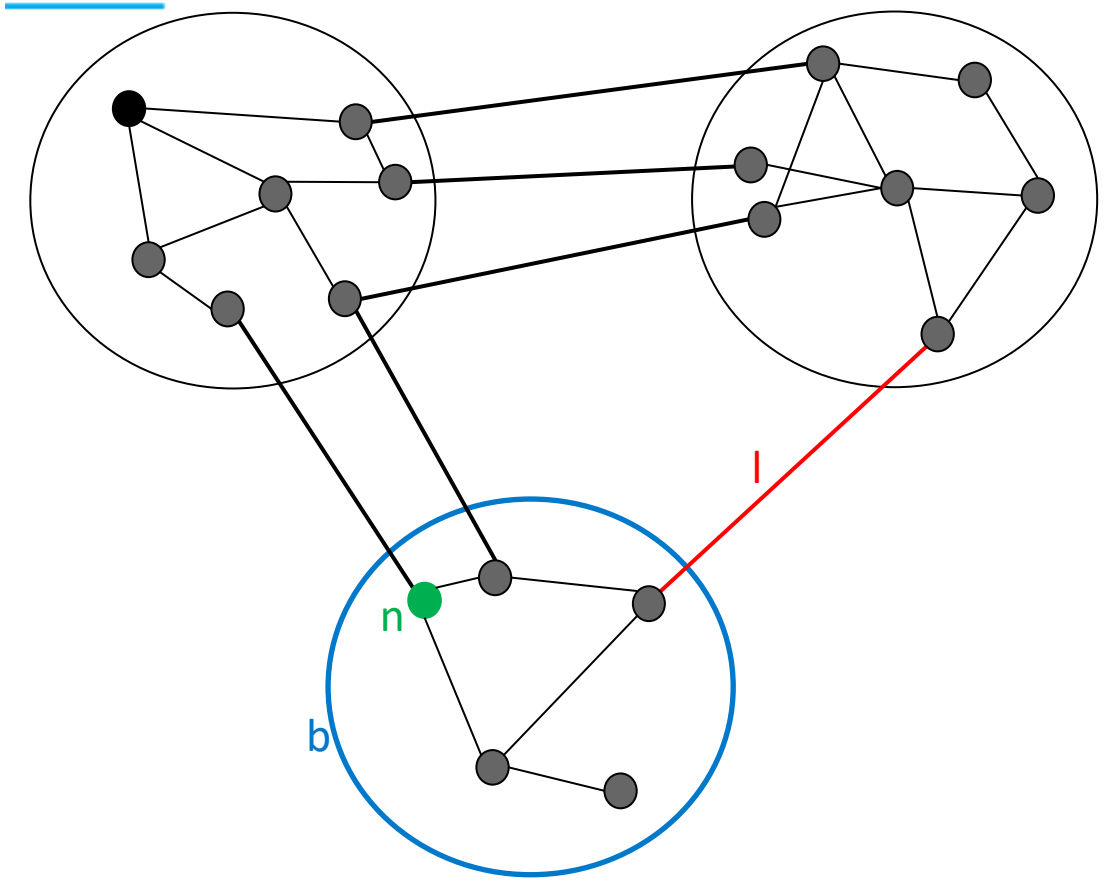
$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{\lim}$$

GSK

Forecast

SINTEF

From Nodal PTDFs to Bidding Zone PTDFs using Shift Keys



The Generation Shift Key (**GSK**) is a value used in the translation from node-to-CNE PTDFs to zone-to-CNE PTDFs.

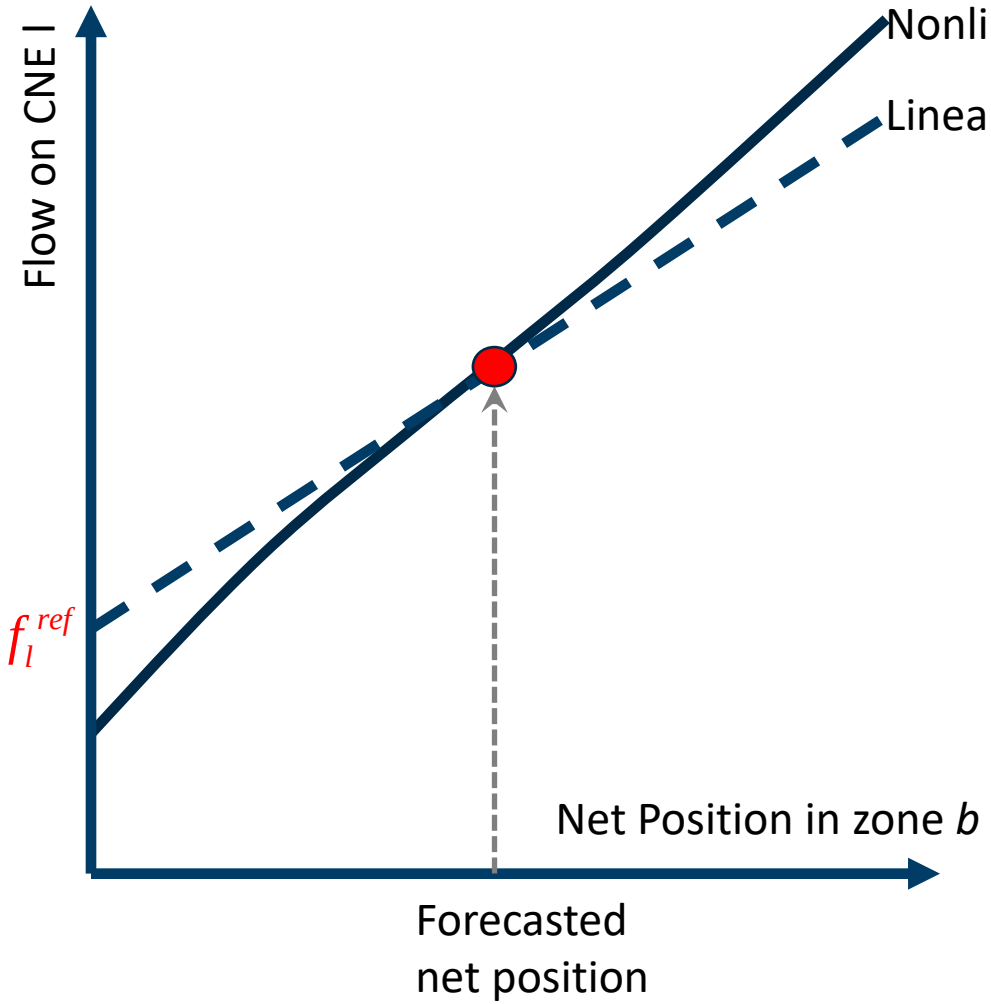
$$PTDF_l^b = \sum_{n \in N_b} GSK^n \times PTDF_l^n$$

$PTDF_l^b$	PTDF for zone b on CNE l ("Zonal PTDF")
GSK^n	GSK for node n
$PTDF_l^n$	PTDF for node n on CNE l ("Nodal PTDF")
N_b	Number of nodes in zone b

In our initial version of the FB procedure, we are opting for a flat GSK strategy. However, the outcome of the flow predictions from different GSK strategies will be monitored over time, which will give a base for developing a potential better strategy in a later version of the Nordic FB.

SINTEF

Use of Forecast for Parameter Estimation



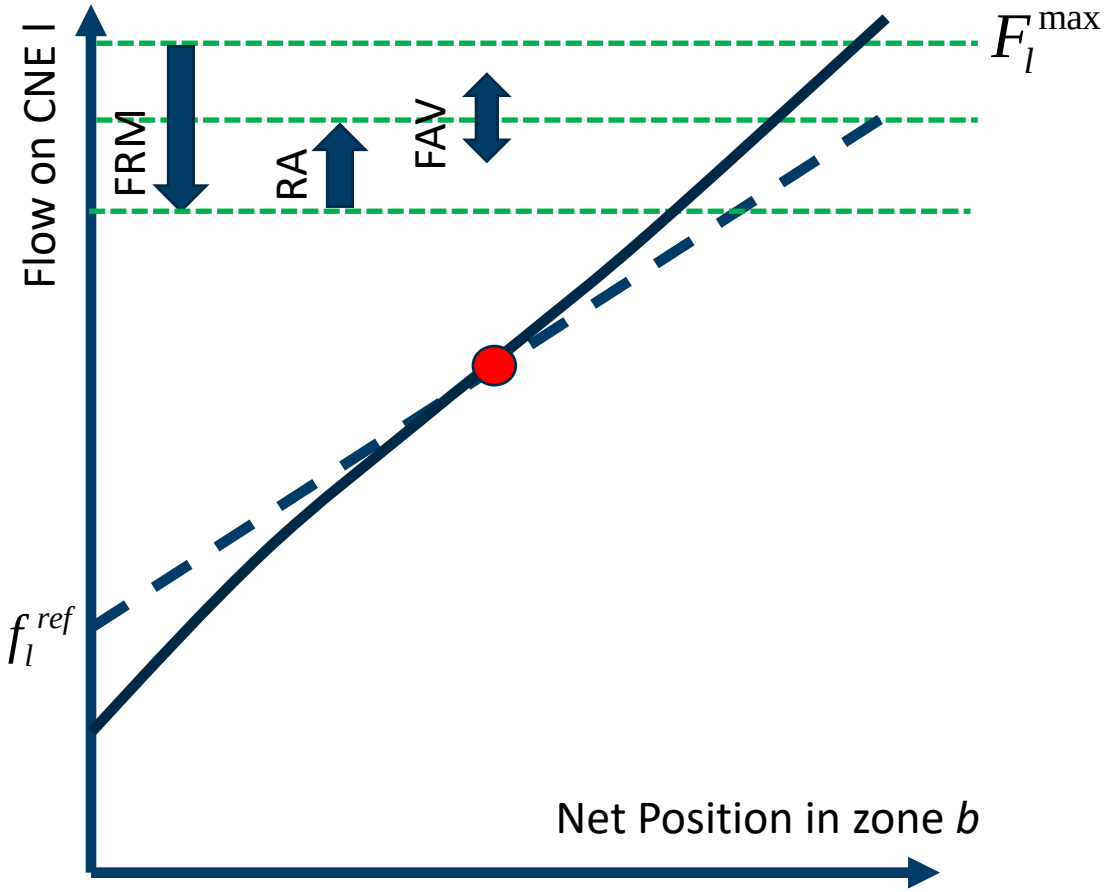
$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{\lim}$$

Note that:

- f_l^{ref} depends on forecasted net position
- Both $PTDF_l^b$ and f_l^{ref} depend on GSK strategy
- $PTDF_l^b$ may depend on forecast, depending on GSK strategy

SINTEF

Estimating Flow Limits on CNEs



$$f_l^{ref} + \sum_{b \in B} PTDF_l^b \times NP^b \leq F_l^{lim}$$

$$F_l^{lim} = F_l^{max} - FRM_l + RA_l - FAV_l$$

$$RAM_l = F_l^{lim} - f_l^{ref}$$

$$\sum_{b \in B} PTDF_l^b \times NP^b \leq RAM_l$$

FRM – Flow Reliability Margin (ch 4.8.2)
RA – Remedial Actions (ch 4.9.2)
FAV – Final Adjustment Value (ch 4.9.2)
RAM – Remaining Available Margin