

The wonderful World of Flow-Based MC

Frank Boerman ir.
Flow Based Capacity Calculation Expert, TenneT



Who am I

- Electrical Engineer msc
- Process specialist TenneT NL System Operations since March 2021
- Mainly working on monitoring and analysis within SOP
 - With Python!
 - Main topic: Flowbased capacity calculation
 - Fascination with Market Design
- Also make multiple public publications:
 - Blog: <https://boerman.dev/>
 - Public dashboards: <https://data.boerman.dev/>
 - Interactive reports: <https://reports.coreflowbased.eu/>
 - LinkedIn: <https://www.linkedin.com/in/frank-boerman-477613164/>
 - And sometimes in traditional media (tv, papers)
- Questions: frank.boerman@tennet.eu



Frank Boerman



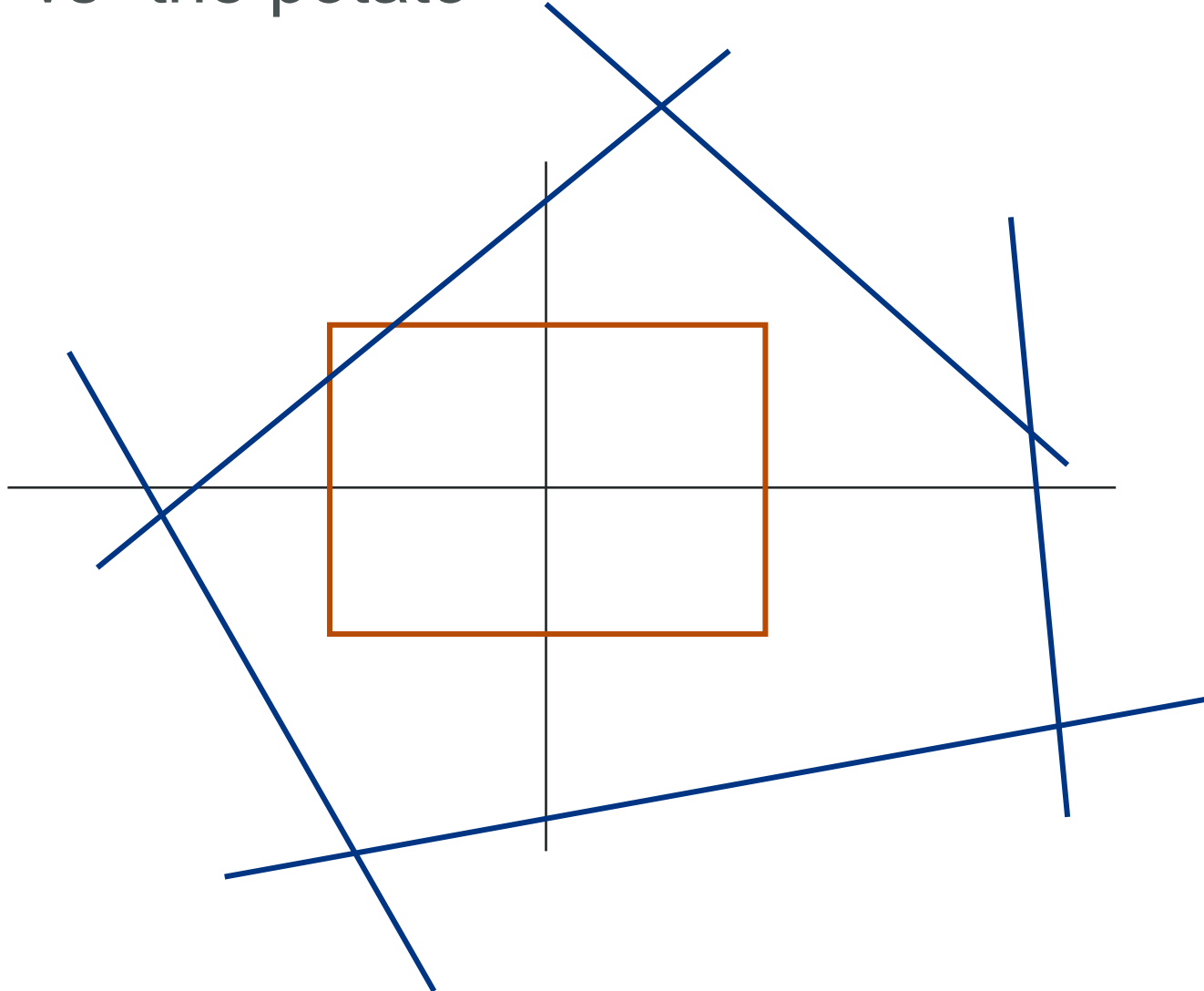
History of Flowbased CORE DA

- CWE running since 2015
- Final form of CORE methodology published in February 2019 (after ACER escalation)
- CORE successfully gone live on 2022-06-09
 - Market coupling between Croatia and Hungary implemented as a subgoal
- Many partners: 16 TSO's, 13 NRA's and 7 NEMO's
- 13 countries
- 12 bidding zones
- 2 virtual hubs (for ALEGRO)
- Future improvements:
 - Merging with IT-NORTH and Ireland (Central CCR)
 - Advanced Hybrid Coupling (2025!)



What is Flowbased?

ATC vs “the potato”



The Flow-based Domain

- A linear algebra constraint matrix
 - Everything is linearized!
- Constraints: CNEC -> N-1 situation
- Has sensitivities to each hub (PTDF's) (the matrix)
- Has a maximum load it can handle: Remaining Available Margin(RAM) (the constraint value)
- Has a list of hubs (the vector) **NOTE: these are the net positions within CORE only!**
- This results in:
 - $PTDF_{hubA} \cdot NP_{hubA} + \dots + PTDF_{hubn} \cdot NP_{hubn} \leq RAM$
- There is also a separate LTA domain
 - Defined per border

$$\begin{aligned} & \min x_1 \\ & \text{subject to } x_1 + 3x_2 \leq -4 \\ & \quad 2x_1 + 0x_2 \leq -2 \\ & \quad \text{for } x_1, x_2 \in \mathbb{R} \end{aligned}$$

Overall Process

Very simplified high-over:

1. Initial data gathering
2. Initial computation -> published!
3. CNEC selection (5% threshold)
4. Non Costly Remedial Action Optimization (NRAO)
5. Intermediate computation-> published!
6. TSO Capacity Validation phase
7. Final computation-> published!

Common myths and misunderstandings

- Many things to look at, but many things can be misunderstood
- Lets highlight some common myths and misunderstandings

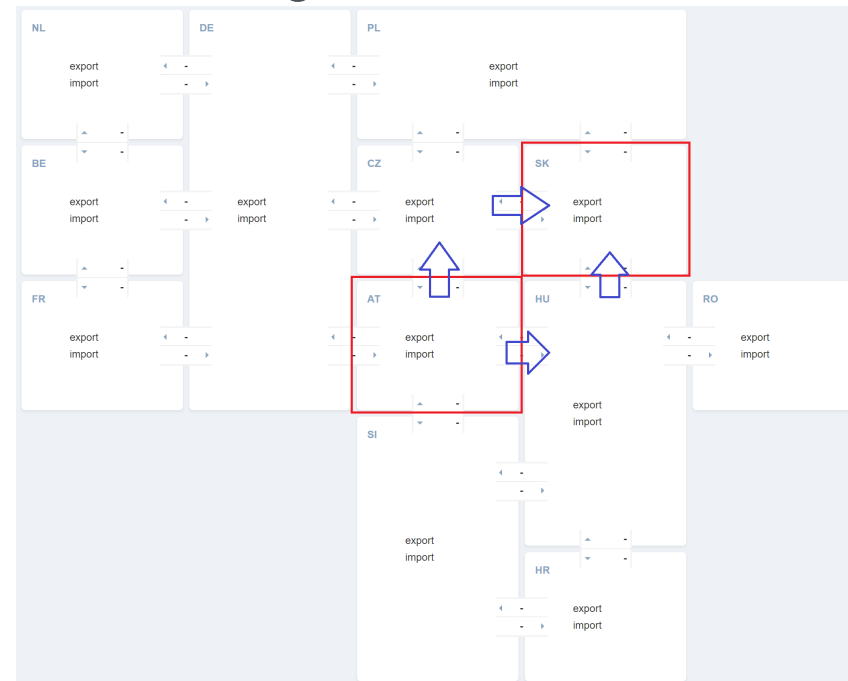
MYTHS
BUSTED

MaxBex (Maximum Bilateral Exchange)

- Statement: MaxBex is like a pseudo ATC (Available Transfer Capacity) on a border
- Right or wrong?



- MaxBex calculates the maximum possible exchange between two zones *taking into account all paths*
- Example: AT->SK has no physical IC, but does have an MaxBex!



Shadow prices

- Statement: a shadow price shows how much lower the Day Ahead price would be, if that constraint is relaxed
- Right or wrong?

WRONG!

Active constraints for TennetBv on 2024-09-17

MTU	Critical Network Element	Contingency	Shadow Price [€/MW]	RAM [% of Fmax]	IVA [% of Fmax]	RAM	Fmax
2024-09-17 00:00	PST MEE 2	N-1 Diele - Meeden WEISS/W	€69.91	21.96%	0.00%	231 MW	1052 MW
2024-09-17 01:00	PST MEE 2	N-1 Diele - Meeden WEISS/W	€59.33	23.48%	0.00%	247 MW	1052 MW
2024-09-17 02:00	PST MEE 2	N-1 Diele - Meeden WEISS/W	€52.85	27.09%	0.00%	285 MW	1052 MW
2024-09-17 03:00	PST MEE 2	N-1 Diele - Meeden WEISS/W	€21.70	27.47%	0.00%	289 MW	1052 MW
2024-09-17 13:00	Maasbracht - Eindhoven 380 Zwart	N-1 Van Eyck - Maasbracht 380 Black/27	€7.07	58.94%	0.00%	1154 MW	1958 MW
2024-09-17 14:00	Maasbracht - Eindhoven 380 Zwart	N-1 Van Eyck - Maasbracht 380 Black/27	€5.25	58.38%	0.00%	1143 MW	1958 MW
2024-09-17 15:00	Maasbracht - Eindhoven 380 Zwart	N-1 Van Eyck - Maasbracht 380 Black/27	€9.37	59.60%	0.00%	1167 MW	1958 MW

- Shadow prices are the amount of welfare that would result in 1MW more RAM
 - And only valid for that first 1MW!

Validation Phase

- Statement: TSO capacity validation is done on individual TSO basis
- Reminder: TSOs lower RAM if (and only if!) there is not enough remedial actions to safeguard the system
- Right or wrong?

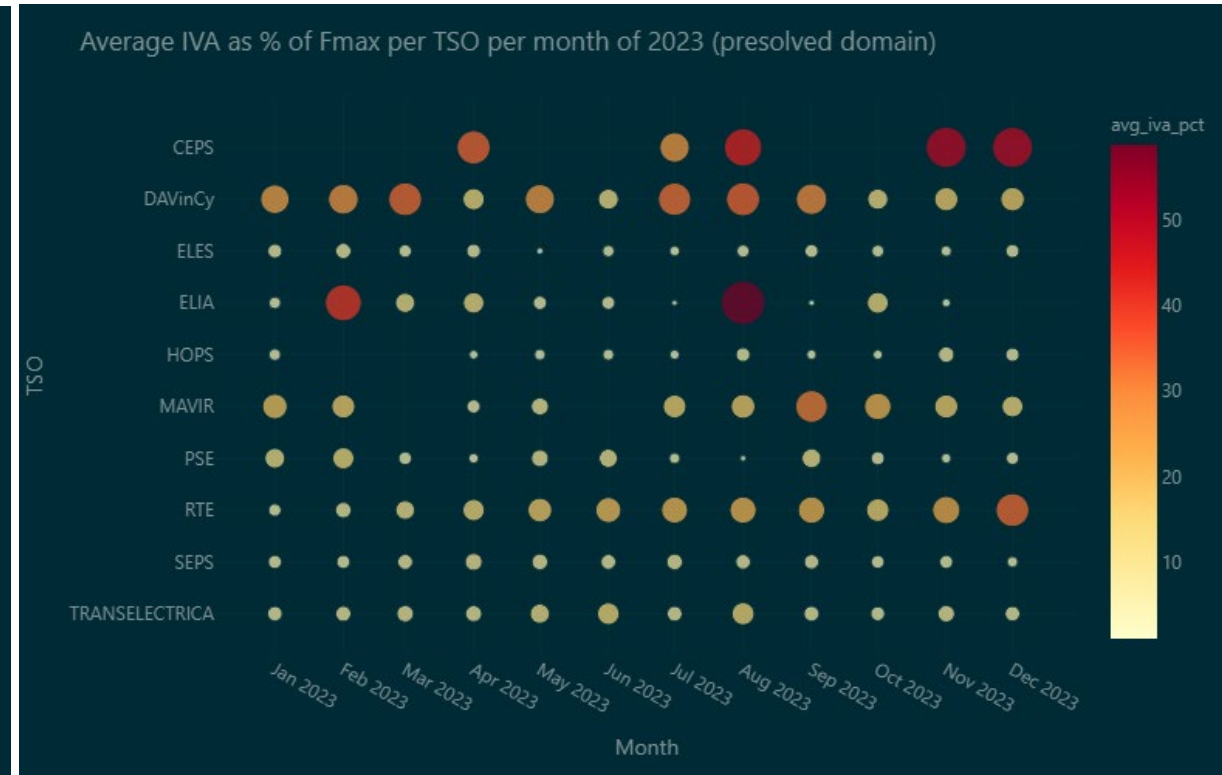
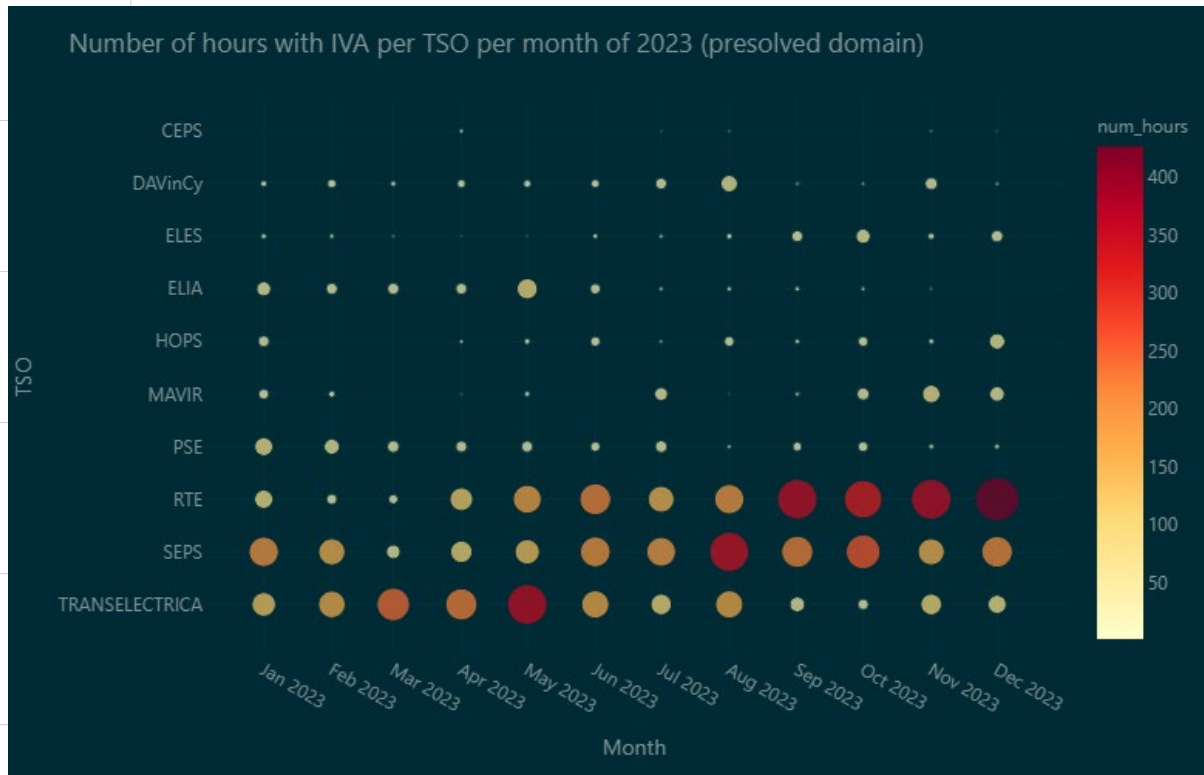


- A.t.m. only the Individual Validation is currently implemented, values determined per TSO
- BUT: German, Austrian and Dutch TSO's pool together their tooling -> DAVinCy
- More information on TSO's IVA methodology [here](#)

MTU	TSO	Critical Network Element	Contingency	Shadow Price [€/MWh]	RAM [% of Fmax]	IVA [% of Fmax]	Max Zone to Zone PTDF	122 PTDF Hub From	122 PTDF Hub To
2024-09-13 09:00	App	Oberselsach - Pöding 247	N-1 Cirkvice-Pöding	€17.20	23.16%	47.41%	18.46%	AT	SI
2024-09-13 09:00	TennetBv	Krimpen a/d IJssel - Oertralsenberg 380 Wit	N-1 Krimpen a/d IJssel-Oertralsenberg 380 Z	€96.92	41.52%	37.23%	49.63%	NL	BE
2024-09-13 10:00	Amprion	Erndorf - Vggy VIGY2 S	N-1 Erndorf - Vggy VIGY1 N	€140.12	24.73%	16.03%	22.31%	FR	CZ
2024-09-13 11:00	App	Westdorf - Oyoe 4398	N-1 Buaers - Westtrioi ws 14213	€19.43	35.10%	38.80%	26.00%	FR	AT
2024-09-13 11:00	App	Zurndorf - Oyoe 4398	N-1 Szombathely - Zurndorf	€197.38	18.83%	36.22%	26.74%	AT	HU
2024-09-13 12:00	Amprion	Erndorf - Vggy VIGY2 S	N-1 Erndorf - Vggy VIGY1 N	€183.77	36.04%	11.15%	22.35%	FR	CZ
2024-09-13 12:00	Amprion	Maasbracht - Oberzier 380 white	N-1 ALEGRO DC	€184.46	20.03%	44.75%	22.83%	BE	CZ
2024-09-13 13:00	Amprion	Maasbracht - Oberzier 380 white	N-1 ALEGRO DC	€87.91	20.03%	46.48%	22.74%	BE	CZ
2024-09-13 13:00	Amprion	Erndorf - Vggy VIGY2 S	N-1 Erndorf - Vggy VIGY1 N	€232.88	19.96%	28.82%	22.19%	FR	DE
2024-09-13 13:00	App	Pleinting - St. Peter 258	N-1 Pirach - Pleinting 256/257	€19.27	20.15%	54.85%	10.25%	DE	AT
2024-09-13 13:00	App	Westdorf - Oyoe 4398	N-1 Buaers - Westtrioi ws 14213	€41.16	20.10%	60.60%	20.09%	FR	AT
2024-09-13 13:00	App	Zurndorf - Oyoe 4398	N-1 Szombathely - Zurndorf	€184.07	18.83%	32.18%	26.49%	AT	HU
2024-09-13 14:00	Amprion	Maasbracht - Oberzier 380 white	N-1 ALEGRO DC	€236.97	20.03%	46.59%	22.74%	BE	CZ
2024-09-13 14:00	App	Pleinting - St. Peter 258	N-1 Pirach - Pleinting 256/257	€23.12	20.33%	64.47%	9.30%	DE	AT
2024-09-13 14:00	App	Oberselsach - Pöding 247	N-1 Cirkvice-Pöding	€93.58	23.43%	56.85%	19.19%	AT	SI
2024-09-13 14:00	App	Zurndorf - Oyoe 4398	N-1 Szombathely - Zurndorf	€271.84	18.76%	33.65%	27.03%	AT	HU
2024-09-13 15:00	App	Zurndorf - Oyoe 4398	N-1 Szombathely - Zurndorf	€268.10	18.76%	34.54%	26.88%	AT	HU
2024-09-13 15:00	TransnetBW	Kaalmoss - Laufenburg ga (Seelbach)	N-1 Laufenburg - Trossingen rt	€725.14	19.99%	39.79%	6.16%	FR	DE
2024-09-13 17:00	App	Zurndorf - Oyoe 4398	N-1 Szombathely - Zurndorf	€359.70	18.54%	52.45%	26.35%	AT	HU
2024-09-13 21:00	Amprion	Erndorf - Vggy VIGY2 S	N-1 Erndorf - Vggy VIGY1 N	€14.45	29.83%	24.52%	21.39%	FR	PL

IVA recap of 2023

- From my blogpost: <https://boerman.dev/posts/yearinreview/iva2023/>
- Large differences between how often and how much IVA is applied



Intermetzo: Min Max NP

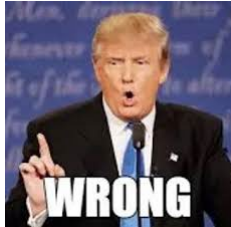
- When looking at a linear algebra matrix it is possible to calculate theoretical bounds of the free variables
- In flowbased -> theoretical minimum and maximum of NetPosition of a hub within CORE
- Trivial to calculate on the domain itself
 - BUT: for market coupling there is also the LTA domain
- To get the correct value -> merge LTA and FB domain
 - This is done through a convex hull
- Published on JAO publication tool

The screenshot shows the 'JAO Publication Tool' interface with the 'Max Net Positions' table. The table has columns for Date, Min values for countries ALBE, ALDE, AT, BE, CZ, DE, FR, HR, HU, NL, PL, RO, SI, SK, and Max values for the same countries. The data is filtered for the date 2024-09-18 and the time slot 00:00-01:00. A 'Download' button is visible in the top right corner of the table area.

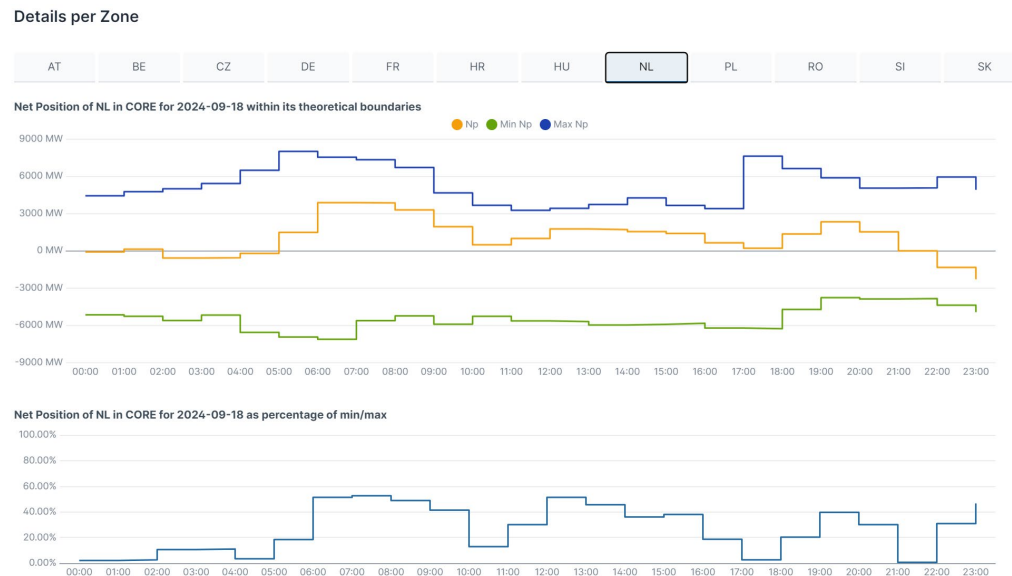
Date	Min ALBE	Min ALDE	Min AT	Min BE	Min CZ	Min DE	Min FR	Min HR	Min HU	Min NL	Min PL	Min RO	Min SI	Min SK	Max ALBE	Max ALDE	Max AT	Max BE	Max CZ	Max DE	Max FR	Max HR	Max HU	Max NL	Max PL	Max RO	Max SI	Max SK
2024-09-18 00:00:00	-1000	-1000	-7279	-8859	-7567	-16729	-11150	-5271	-7084	-5166	-4212	-2842	-3915	-6992	1000	1000	6268	7315	9844	12936	7832	3999	5848	4418	4459	2409	6905	6379
2024-09-18 01:00:00	-1000	-1000	-7717	-8986	-7643	-16992	-11294	-5455	-7117	-5282	-4142	-2914	-4007	-6865	1000	1000	5913	7506	9939	14490	7880	3404	6029	4745	4425	2355	6876	6325
2024-09-18 02:00:00	-1000	-1000	-7698	-9309	-7759	-16874	-11606	-5517	-7164	-5630	-4245	-2732	-4096	-6829	1000	1000	5915	7271	10000	15131	7456	3767	6082	4978	4362	2487	6811	6384
2024-09-18 03:00:00	-1000	-1000	-7676	-9301	-7923	-17380	-11710	-5412	-7108	-5196	-4211	-2710	-4090	-6787	1000	1000	5852	6895	10136	15375	6715	3906	6072	5401	4394	2444	6788	6348
2024-09-18 04:00:00	-1000	-1000	-7543	-9134	-7823	-17460	-12354	-5525	-6849	-6585	-4250	-2649	-4076	-6660	1000	1000	6024	7165	10045	15085	7092	3832	5897	6464	4358	2393	6777	6258
2024-09-18 05:00:00	-1000	-1000	-7283	-9581	-7786	-17682	-12464	-5489	-6651	-6956	-3868	-2806	-3800	-6436	1000	1000	6393	6791	10090	15772	7354	4107	5097	7993	4638	2077	6961	6153
2024-09-18	-1000	-1000	-6144	-9637	-7814	-17163	-12592	-6286	-7563	-7137	-3903	-1467	-4274	-6723	1000	1000	4730	7094	9835	16516	7311	3210	5856	7523	4498	3289	6294	6487

Min Max Net Position Utilization

- Statement: when there is price divergence close to 100% of the min/max NP of a hub is used
- Right or wrong?



- Min Max NP is usually a very extreme of the domain and hard to reach realistically
- Euphemia is a regional optimization! Usually doesnt make sense to push a hub to 100%



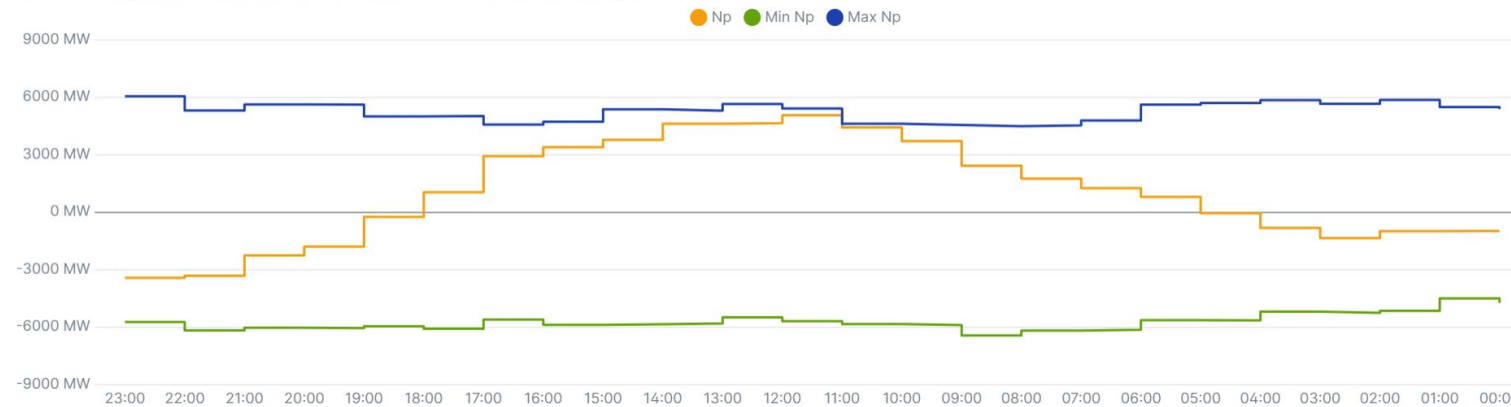
Min Max Net Position Utilization (2)

- It is rare but not impossible!
- Very sunny summer day in NL:

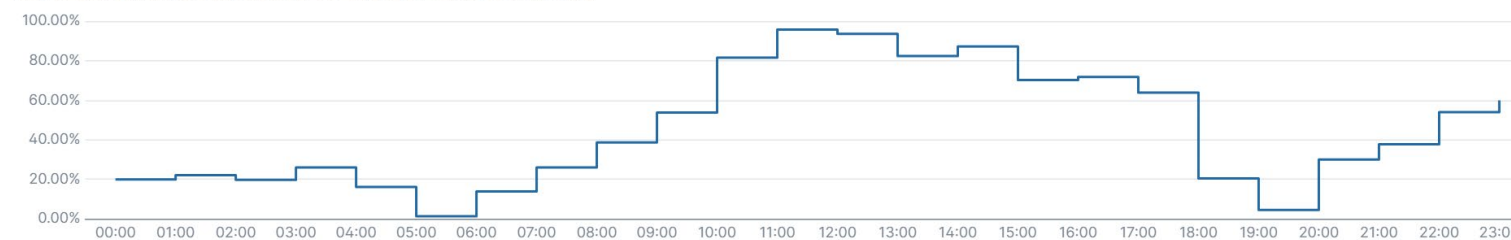
Details per Zone

AT	BE	CZ	DE	FR	HR	HU	NL	PL	RO	SI	SK
----	----	----	----	----	----	----	-----------	----	----	----	----

Net Position of NL in CORE for 2024-06-02 within its theoretical boundaries



Net Position of NL in CORE for 2024-06-02 as percentage of min/max



(Non) Intuitive Flows

- Statement: all scheduled flows go from low to high price zones
- Right or wrong?



- So called non intuitive (high -> low price) flows can exist in SDAC!
- Possible reasons:
 - To relieve a constraint to make possible more welfare gain for different hubs
 - To create transit flows (from high to low to even higher price zone)

(Non) Intuitive Flows Example

- Old example from March 2022
- Flow NL->BE coincides with peaking price delta on BE->FR
 - Blue bar = non intuitive flow on NL->BE
 - Yellow line = BE-FR price delta
- From old blog post: <https://boerman.dev/posts/aten/non-intuitive-flows-1/>

