TECHNISCHE UNIVERSITÄT DRESDEN

Technische Universität Berlin

Faculty of Business and Economics
Chair of Energy Economics, Prof. Dr. Möst

Faculty of Economics and Management
Workgroup for Infrastructure Policy, Prof. Dr. v. Hirschhausen

Impact of Different Generation Shift Key Strategies on the Flow-based Market Coupling Domain in Germany

LKDEU Abschlussworkshop

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David Schönheit TU Dresden
Richard Weinhold TU Berlin
Constantin Dierstein TU Dresden

lkDEU langfristige Planung und kurzfristige Optimierung des **Elektrizitätssystems in Deutschland** im europäischen Kontext

Im Rahmen des vom BMWi geförderten Projektes LKD-EU (FKZ: 03ET4028C)

Agenda

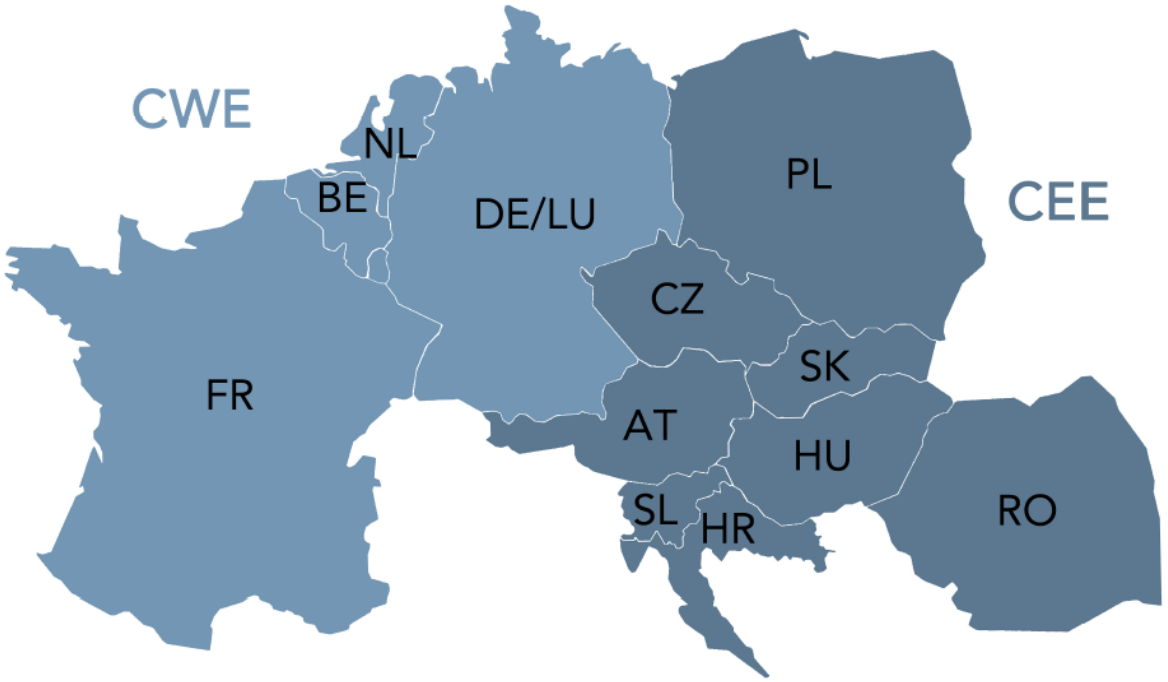
1. **Background and research question**
2. Methodology
3. Model
4. Results and implications
5. Conclusion

1. Background: **Market coupling – Flow-based as the preferred method**

- **Market coupling (MC)** matches the bids of national power exchanges
- TSOs determine **capacity limits** for cross-border flows they allocate to the MC algorithm
- This is realized through **NTC/ATC** or **Flow-based (FB) constraints**

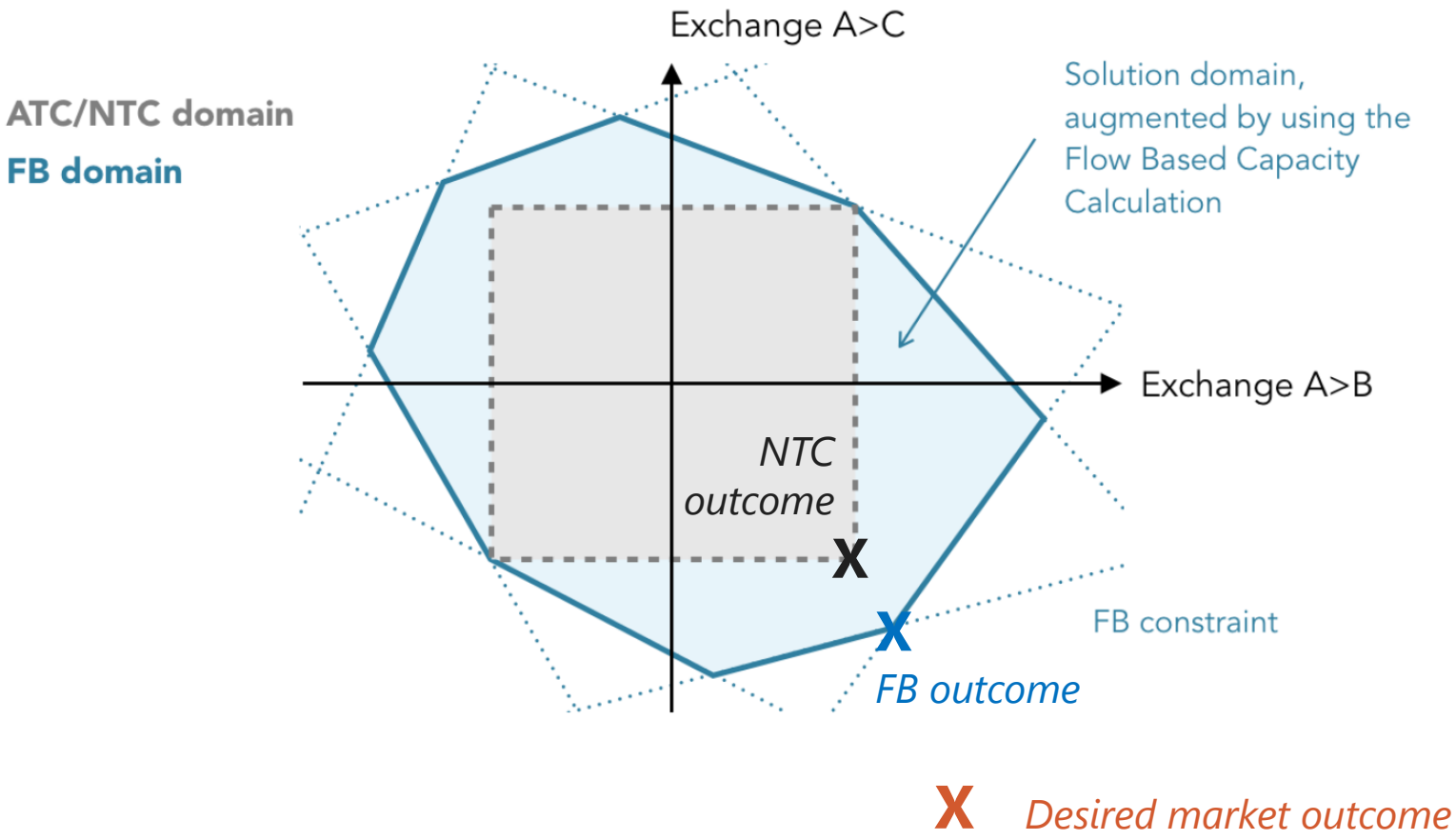
- FBMC was tested in CWE parallel to the NTC/ATC (2013-2014) and launched in in 2015
  - Incorporation of the grid and its constraints
  - Greater price convergence and welfare increases
- Commission Regulation (EU) 2015/1222: **Flow-based market coupling as preferred method for calculating cross-zonal capacities**
- Recent efforts aim to implement FBMC in Core Region (CWE and CEE)

➢ **Goal to model main uncertainties of flow-based market coupling methodology within LKD-EU**



Altered figure based on ENTSO-E 2015

1. Background: **Market coupling – Flow-based as the preferred method**



Own diagram based on Amprion et al. 2011 and Energinet.dk et al. 2014

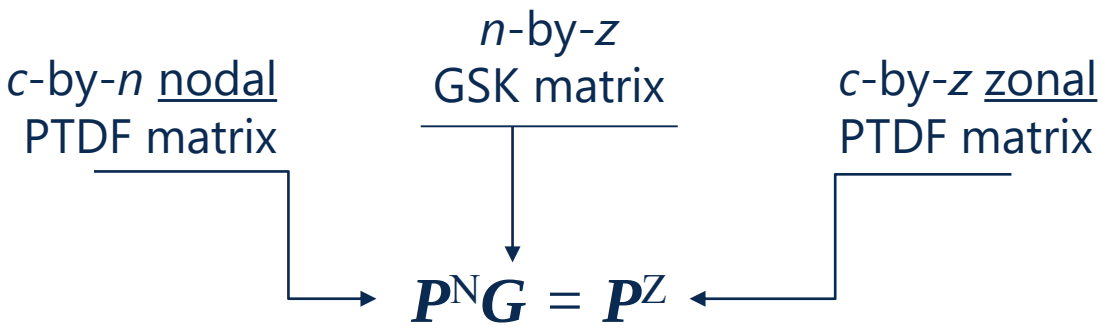
1. Background: **Generation Shift Keys (GSKs) – A key uncertainty in FBMC**

Generation Shift Keys: $\Delta G_k / \Delta NP_z$

Net position change: $\Delta NP_z = NP_{z,i} - NP_{z,ref}$

D-1 **D-2** (Base Case)

- GSKs attempt to predict how changes in a market area's net position affect the individual outputs of the area's generating units
- **GSKs weight the nodal PTDF* values to obtain zonal PTDF values**



z – zone
n – node
c – critical network element

* Power Transfer Distribution Factor

1. Background: **Flow-based domain parameters**

Remaining Available Margin:

$$RAM+_c = F_{max} - FRM_c - FAV_c - F_{ref,c}$$

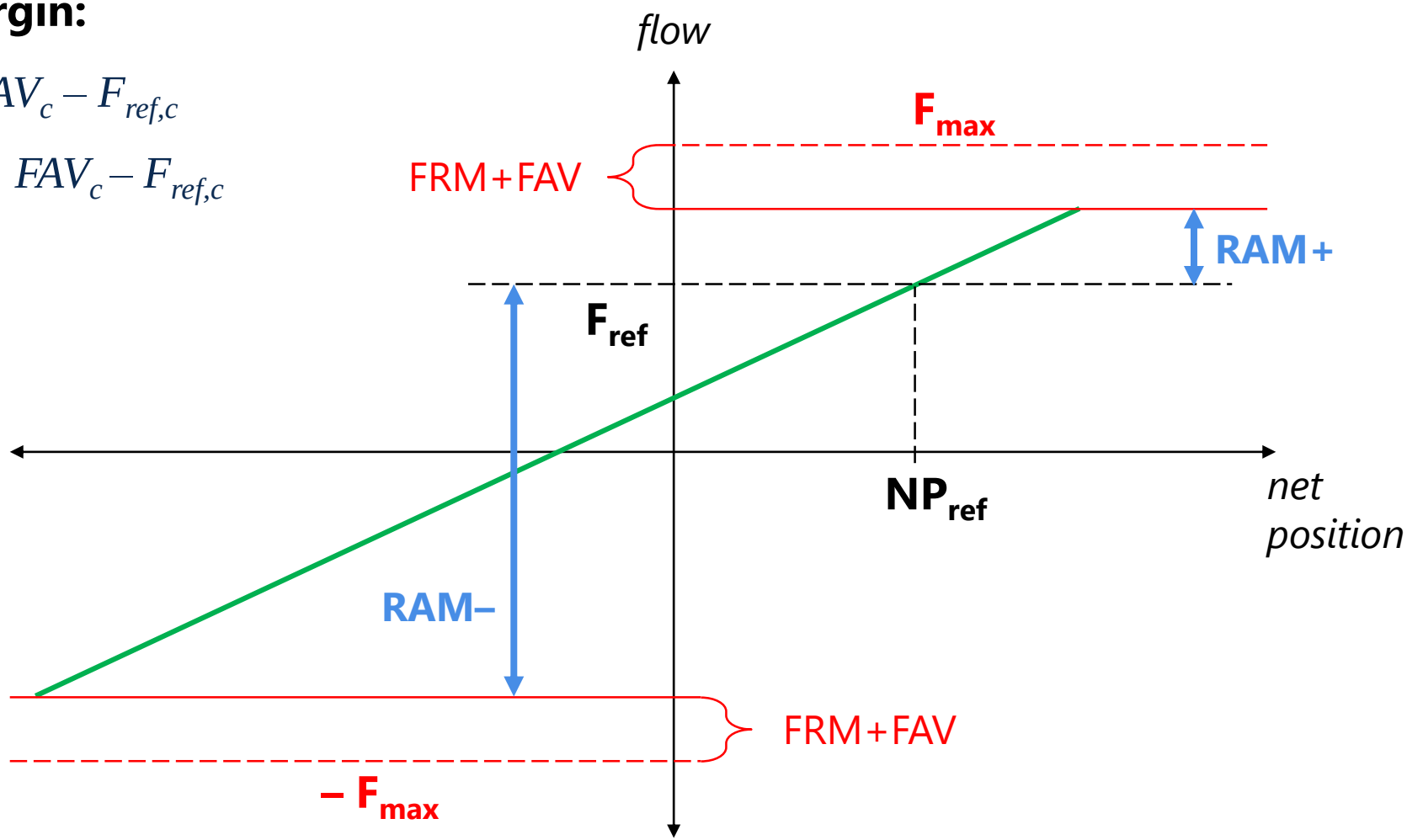
$$RAM-_c = -F_{max} + FRM_c + FAV_c - F_{ref,c}$$

Flow change:

$$\Delta F_c = \sum_z PTDF_{z,c} \cdot \Delta NP_z$$

$$\Delta F_c \leq RAM+_c$$

$$\Delta F_c \geq RAM-_c$$



Own figure based on Energinet.dk et al. 2014 and Amprion et al. 2011

1. Background: **Research question**

What is the impact of different Generation Shift Key strategies on the Flow-based market coupling domain in Germany?

Why is it important:

The importance of GSK strategies is discussed in official documents and academia but the effect of different strategies on the FBMC domain and individual network elements has not been thoroughly researched for Germany (or for CWE)

What it is not about:

The goal is not to identify better or worse GSK strategies (among the tested) but to quantify the GSK strategy's effect on the FB domain and criticial network elements

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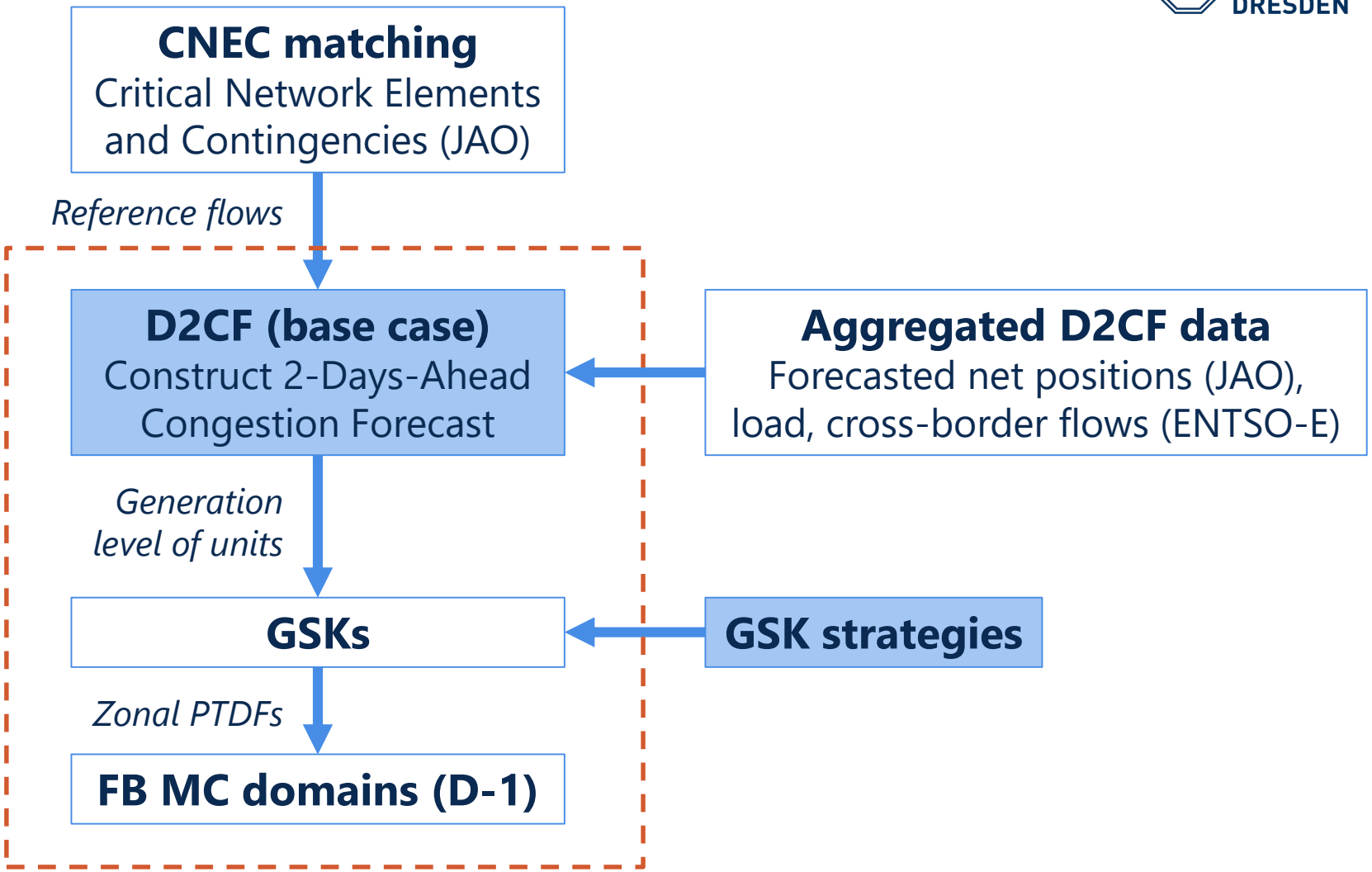
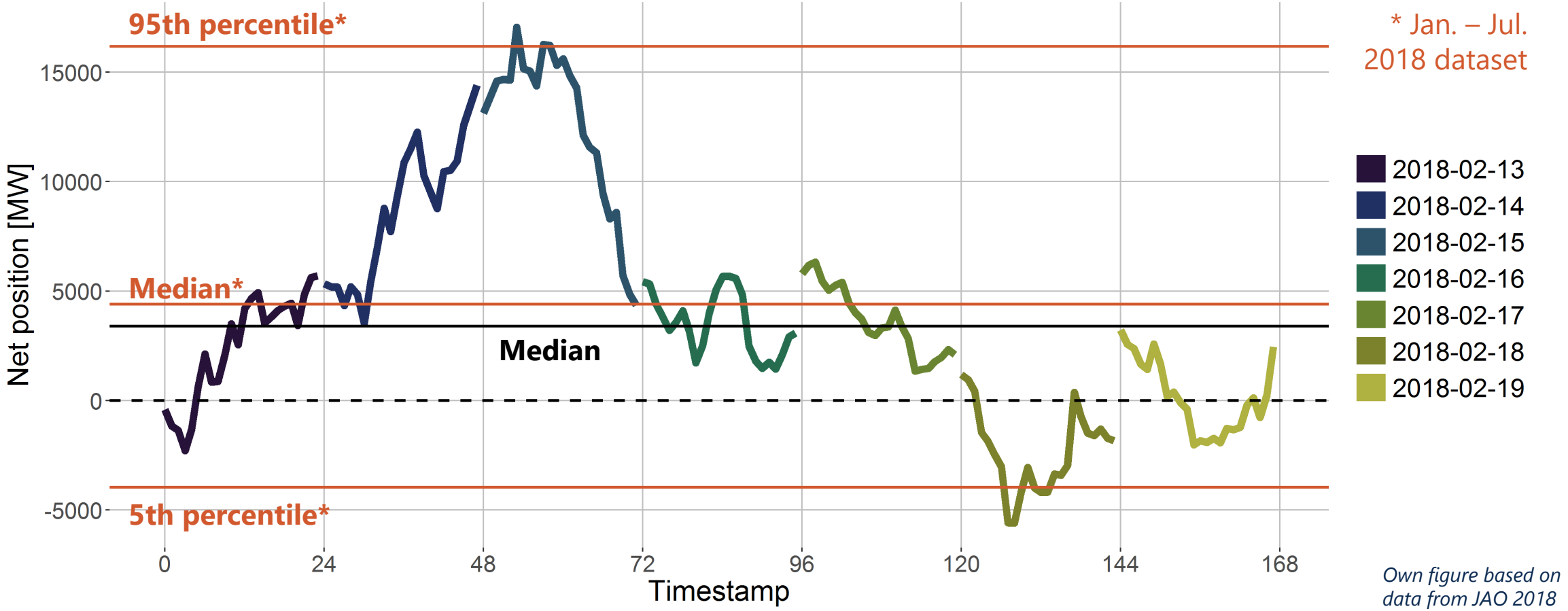
2. Methodology: **Approach**



2. Methodology: **Considered timeframe – A representative week**

D-2 forecasted net position of Germany: February 13-19, 2018



* Jan. – Jul. 2018 dataset

Own figure based on data from JAO 2018

2. Methodology: **Matching of CNEs and their reference flows for base case and domain construction**

Example for entries in daily CNEC file:

Critical Network Element (CNE)	Outage/Contingency	Remaining Available Margin	Fmax	Fref	FRM	FAV	Bidding Area
L 400kV N0 1 AVELIN-GAVRELLE	N-State	1619	2301	376	306	0	BE
L 400kV N0 1 AVELIN-GAVRELLE	L 400kV N0 1 MERY-SUR-SEINE-VESLE	1548	2301	447	306	0	BE

Matching of the <u>non-anonymized</u> Critical Network Elements to lines in database*

(1) At "N-State" or "Basecase"

(2) Only if line clearly identifiable, otherwise omitted (Example: L 400kV N0 1 AVELIN-GAVRELLE → "I1031")

(3) Identification of flow direction

➢ Identification of over 10,000 CNE (ca. 70 for each of the 168 timesteps)

* More details in Appendix.

2. Methodology: **Tested GSK strategies**

GSK strategy	Generating units weighted according to	Considers dispatch information
Maximum power output	$\mathbf{G_{max}}$	No
Scheduled power output	**G**	Yes
Available margin	$\mathbf{G_{max}}$ **- G**	Only for **G**
Uniform / „flat“ strategy	**1**	No

For $\mathbf{G_{max}}$ strategy weight for unit *k*

$$\frac{G_{max,k}}{\sum_k G_{max,k}} \quad k \in K$$

- **Challenge 1**: correct GSK strategy
- **Challenge 2**: which units *k* to consider (fuels, technologies, only running or also non-dispatched power plants etc.)

- Array of „standard“ GSK strategies used by TSOs
  - All are linked to fixed (G_{max}) or quasi-fixed (G) generating unit parameters
  - Often static or two time categories (e.g. peak and off-peak)
  - Strategies also have to be able to map *negative* and *large* net position changes
- Flow-based market coupling calls for a more flexible GSKs, e.g. Schönheit, Sikora (2018)

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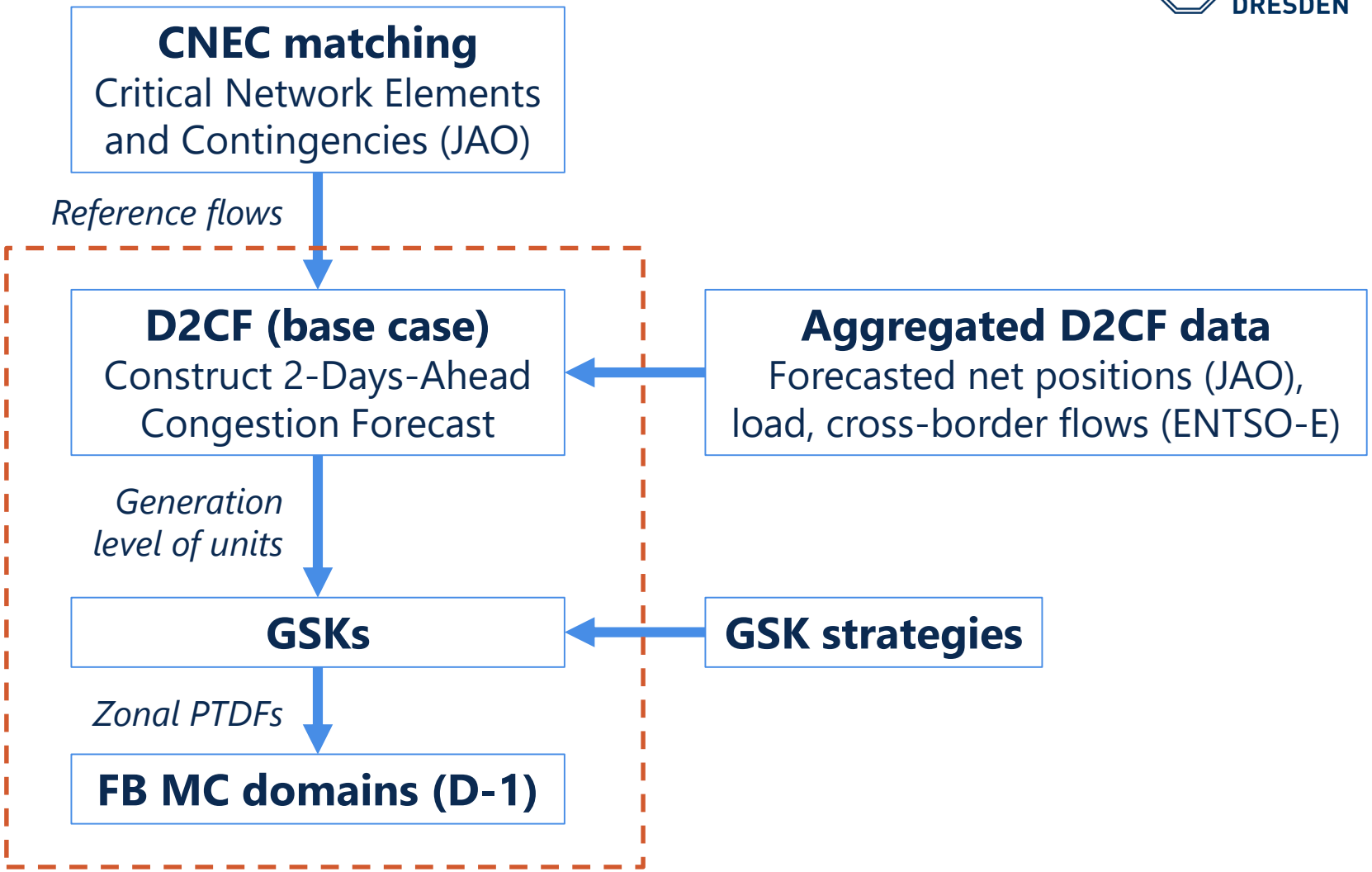
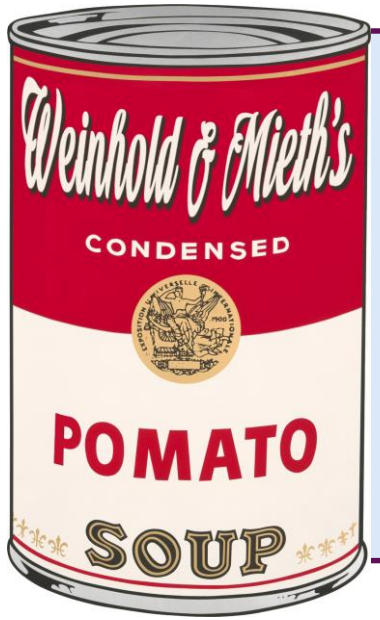
2. Methodology: **Approach**



3. Model: **An Open Source Power Market Model**



Main API: Python
- Data handling
- Grid pre-calculations
- OS independent services
- GNU GPLv3 License

Optimization Kernel
- Julia / JuMP
- Powerful Open Source AML
- Variable solver choice

Open Data
- Open Power System Data
- Grid Data ELMOD

DIW BERLIN

GUI
- Interactive plotting
  - Grid/Gen/Load
- Implemented in Python/Bokeh

- v0.1.0 downloadable on GitHub
- Licensed under GNU GPL v3

3. Model: **Market & Grid Model**

Market Model:

$$\min \sum_{p,t} mc_p \cdot G_{p,t}$$

s.t. Capacity Constraints	$\forall p \in P$
Storage Constraints	$\forall s \in P_s$
Renewable Curtailment	$\forall r \in P_r$
Nodal Demand	$\forall n \in N$
Net Positions	$\forall z \in Z$
Net Export	$\forall z \notin \text{CWE}$
Reference Flows	$\forall cnec \in L$
Line Flows $\leq 0.75 \cdot$ Capacity	$\forall cb \in L$

GSK

Grid Model:

$$\text{Flow}_{l,cb} = (\mathbf{PTDF}_l + \text{LODF}_{l,cb} \cdot \mathbf{PTDF}_{cb}) \cdot \mathbf{INJ}$$
$$\text{RAM}^{+}_{l,cb} = (\text{line}^{max}_{l} - \text{frm\&fav}_l) - \text{Flow}_{l,cb}$$
$$\text{RAM}^{-}_{l,cb} = -(\text{line}^{max}_{l} - \text{frm\&fav}_l) - \text{Flow}_{l,cb}$$

with PTDF an $l \times n$ and LODF an $l \times l$ Matrix

FBMC Domain given by:

$$(\mathbf{PTDF}_l + \text{LODF}_{l,cb} \cdot \mathbf{PTDF}_{cb}) \cdot \mathbf{GSK} \cdot \mathbf{X} \leq \mathbf{RAM}^{+} \quad \forall cb \in L, l \in CNEC$$
$$(\mathbf{PTDF}_l + \text{LODF}_{l,cb} \cdot \mathbf{PTDF}_{cb}) \cdot \mathbf{GSK} \cdot \mathbf{X} \geq \mathbf{RAM}^{-} \quad \forall cb \in L, l \in CNEC$$

Where $\mathbf{X}$ represents the change in Net Position for each market area

FB Domains

Market Data:
Load (ENTSO-E/JAO)
Net Positions (JAO)
Cross-Border flows (ENTSO-E)
RES Timeseries (OPSD/RES Ninja)
Grid Data DE – DIW Data Documentation, CWE – (TBD)
Generation Costs – DIW Data Documentation, Schröder et al.

- The base case employs a myriad of different parameter choices and multiple possible grid configurations
- The GSK can be dependent on the market result
- The domains as a visual output (and the result used in markets)

3. Model: **CNECs – Grid Representation**

Model Scope and included CNECs

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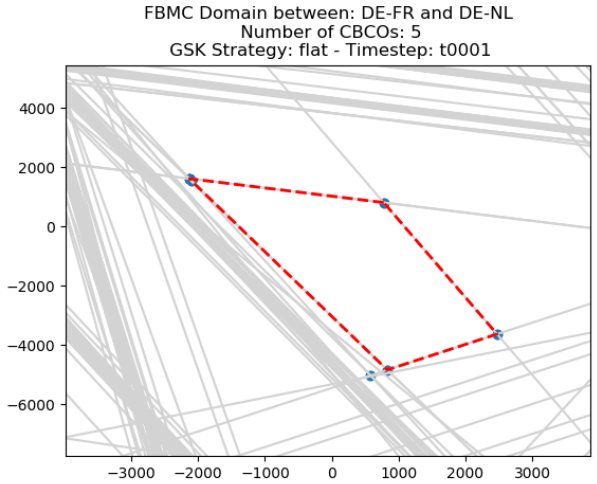
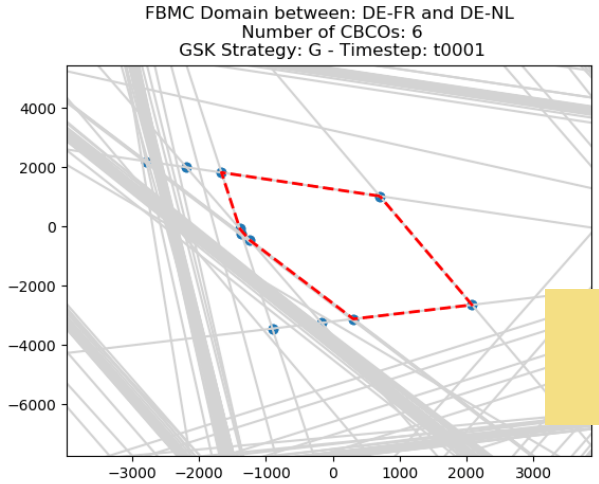
4. Results: **FBMC domains varying across time and GSK strategies**

Flow-based market coupling domain (DE<>FR and DE<>NL) for hour 1 – 24:

Strategy: **Flat**

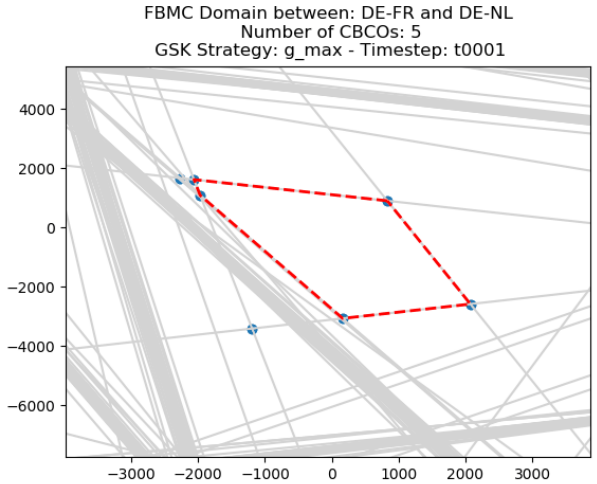


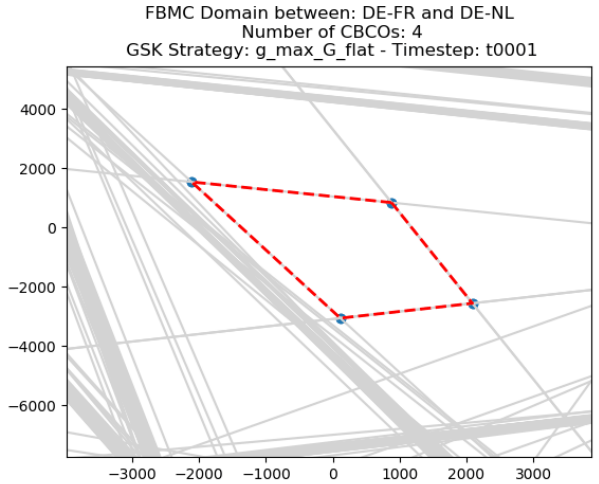


Strategy: **G**

GIF in original presentation

Strategy: **G_{max}**

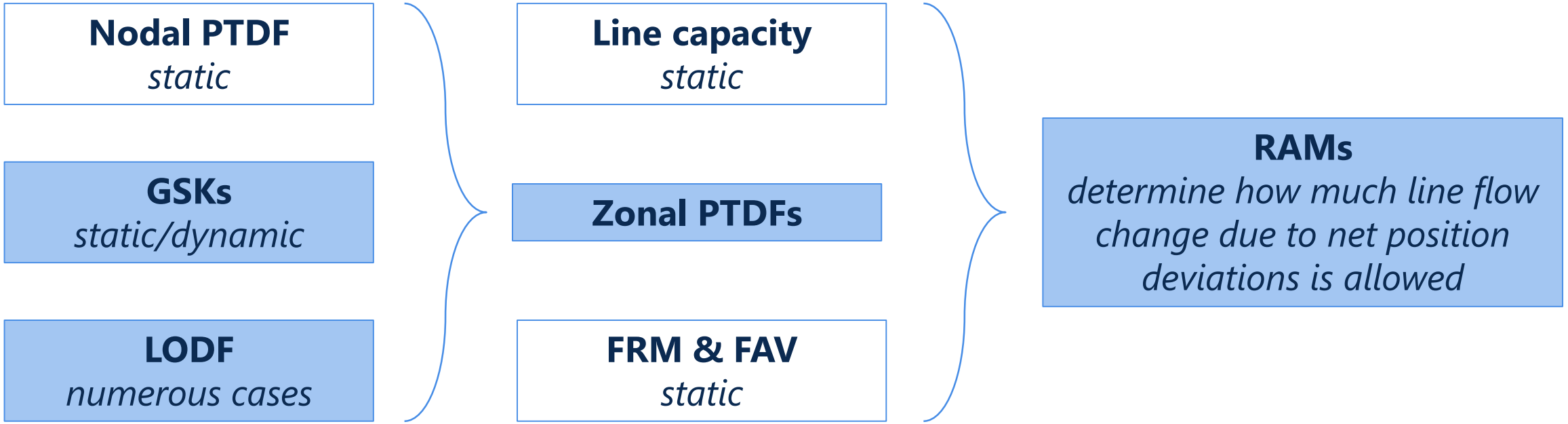




Strategy:

G_{max} – G or Flat

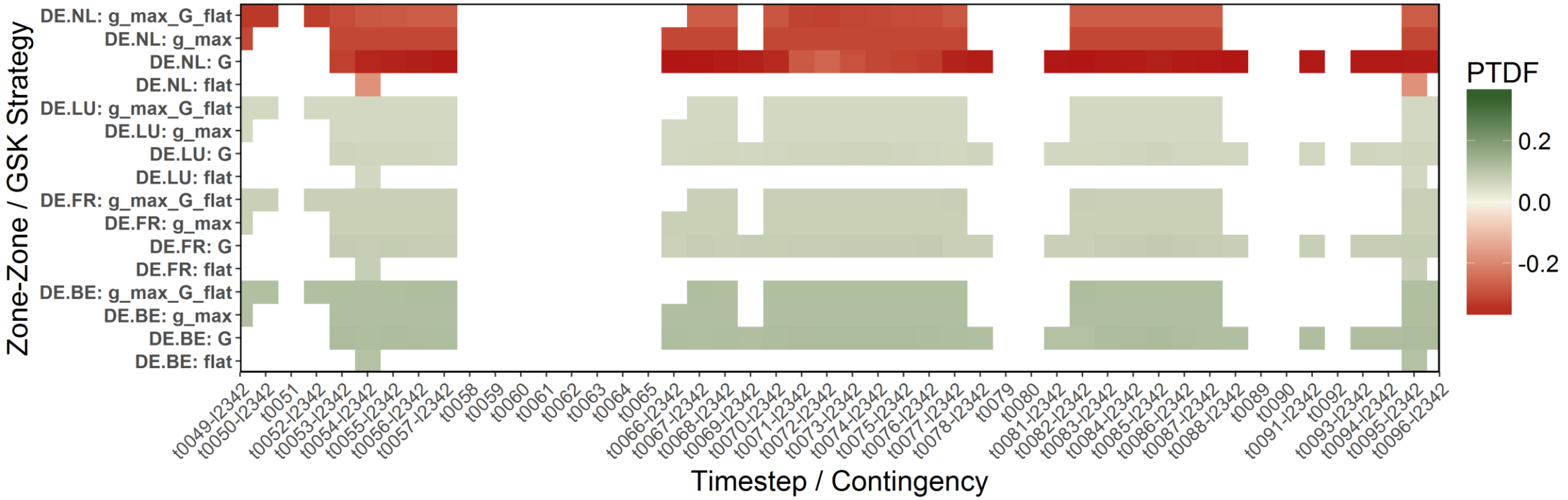
4. Results: **GSKs and contingencies are major determinants of FB domains**



- GSKs and contingencies determine zonal PTDFs and Remaining Available Margins → domain construction
- **CNE-specific evaluation of PTDFs** is needed to quantify the effect of GSKs on the FBMC domain

4. Results: **Example 1 – GSK strategies affect DE-NL PTDFs most substantially**

Zone-to-zone PTDF values – CNE „l1695“ – day 3 & 4

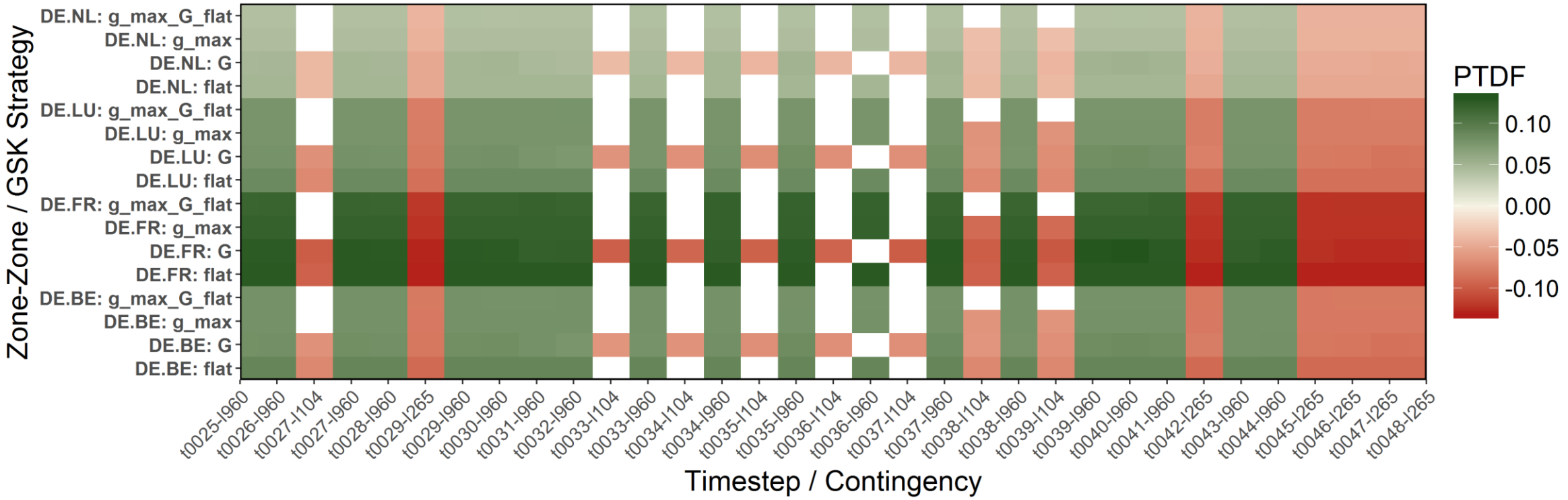


- CNE „l1695“ often constrains domain
- Only under **one** contingency (critical outage) per timestamp (“l2342”)

- **PTDF values** across time and GSK strategies are
  - **Similar** for DE-BE, DE-FR, DE-LU
  - **Varying** for DE-NL

4. Results: **Example 2 – GSK strategies and contingencies affect PTDFs**

Zone-to-zone PTDF values – CNE „I961“ – day 2



- CNE „I961“ almost always constrains domain
- Under **different** contingencies (critical outages) per timestamp (either “I960” or “I104”)

- **Changing PTDF values**
  - Under different GSK strategies
  - Mostly due to different contingencies

4. Results: **Significant differences between PTDF values in „GSK groups“**

One-way ANOVA test for each CNE and for each DE-zone combination:

- F-test on “Between-group variance” / “Within-group variance”
- Test null-hypothesis: PTDF values across all “GSK-strategies groups” have the same expected value
- Test is significant for all CNE and DE-zone combinations, with varying magnitudes of group differences

	p-values of ANOVA test				Maximum difference between GSK „group“ means			
CNE	DE-BE	DE-FR	DE-LU	DE-NL	DE-BE	DE-FR	DE-LU	DE-NL
I71	0.0000				0.0177	0.0122	0.0133	0.0397
I341					0.0146	0.0166	0.0159	0.0233
I787					0.0158	0.0035	0.0123	0.0083
I789					0.0257	0.0061	0.0076	0.0048
I961					0.0083	0.0069	0.0071	0.0065
I1688					0.0052	0.0023	0.0026	0.0900
I1691					0.0052	0.0023	0.0026	0.1010
I1695					0.0054	0.0024	0.0028	0.1042
I1700					0.0163	0.0030	0.0036	0.0366
I1852					0.0193	0.0193	0.0194	0.0140

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5. Conclusion: **Key insights**

Framework

- **GSKs are a major determinant of zonal PTDFs**, used to construct FB market coupling domains
  - Different (not necessarily realistic) GSK strategies are used in academia and by TSOs
  - Generally, the GSK construction is an important task for TSOs to adequately map unit behavior
- **Good representation of the D2CF** (base case) is important to test impact of GSK strategies
  - Proposed approach: Matching of critical network elements and their reference flows for base case

Impact of GSKs on domains and CNECs

- **Domains are often constrained by a few CNECs** (often <10)
  - Importance of correctly weighting the nodes affecting the CNEC the most → GSKs
- **Domains vary in shape and size depending on GSK strategy**, hour of the day and net position
- **Zonal PTDF-values vary across GSK strategies and contingencies**
  - GSK strategies frequently determine if the element constrains the domain

➢ **Proposed approach increases transparency and traceability regarding the effect of GSK strategies**

Thank you for your attention! Questions?

David Schönheit
email: david.schoenheit@tu-dresden.de
phone: +49 (0)351 463 39 766

Richard Weinhold
email: riw@wip.tu-berlin.de
phone: +49 (0)30 314 75 838

Constantin Dierstein
email: constantin.dierstein@tu-dresden.de
phone: +49 (0)351 463 39 769

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