TBM Electricity Price Forecasting & Modeling Forum

Berlin, 25.09.25

BKW

ENERGY

How to simplify flow-based market coupling in long-term modeling?

Content

BKW Group

>12,000
employees

Strong Swiss base with a focus on selected core regions in Europe
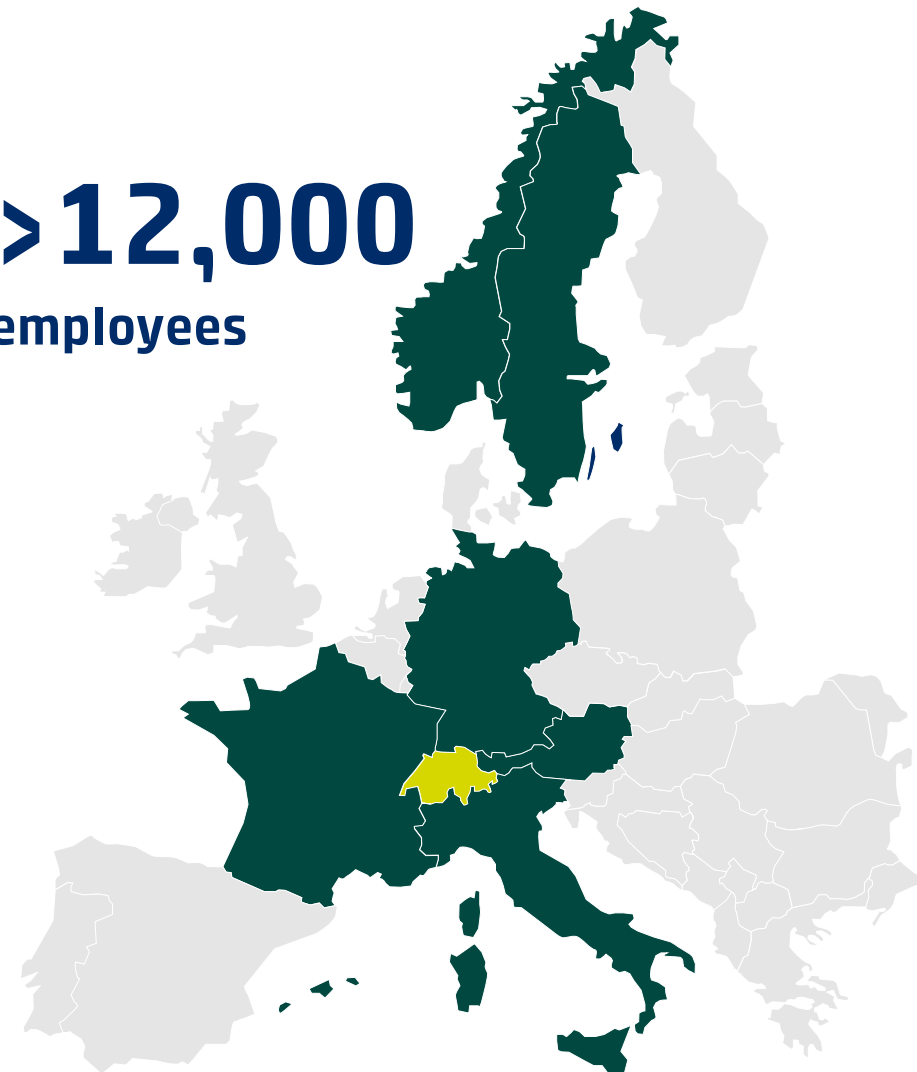
Active in three attractive markets **energy, infrastructure and buildings**

Portfolio covers the **entire energy transition value chain**

We cover the entire energy transition value chain

Our three business segments:

Energy Solutions

– Leading player in the European trading and customer solutions business
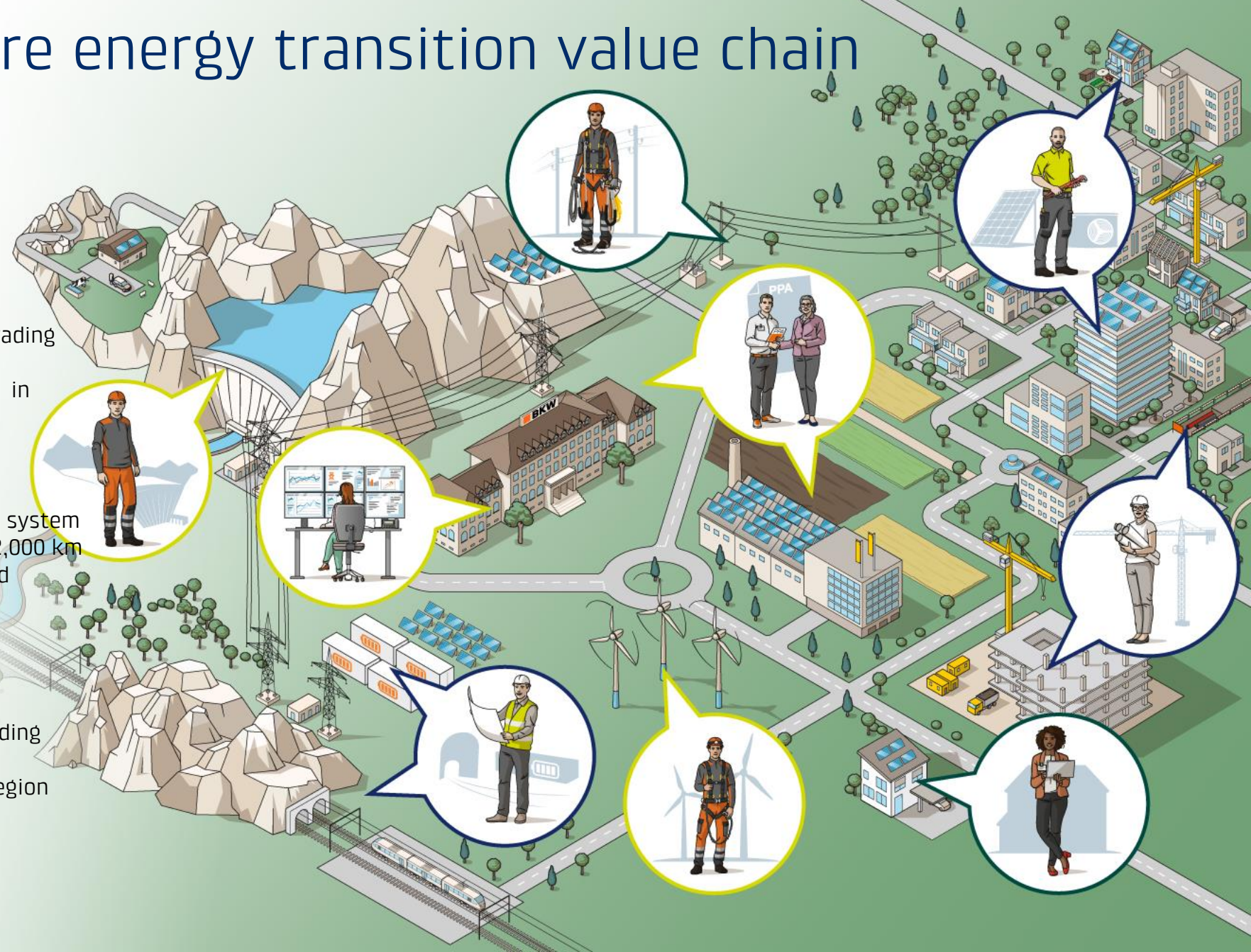– Third-largest electricity producer in Switzerland (9 TWh)

Power Grid

– Switzerland's largest distribution system operator with a grid length of 22,000 km
– Supplies over 1 million people and businesses

Infrastructure & Buildings

– Leader in infrastructure and building solutions
– Over 260 locations in the DACH region

Strategic Market Analysis – Who we are

The daily life of our Strategic Market Analysis Team at BKW

Management support

Regulatory updates for Board members

CEO briefings

Technical support in legal cases and proceedings
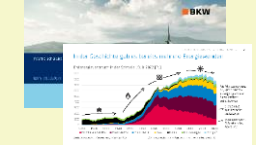
Regulatory overview and briefings for business units
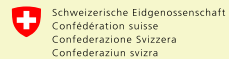
Knowledge sharing

Knowledge sharing platform

Internal lecture series

Training course: "Fundamentals of power markets"

Advocacy and policy influencing
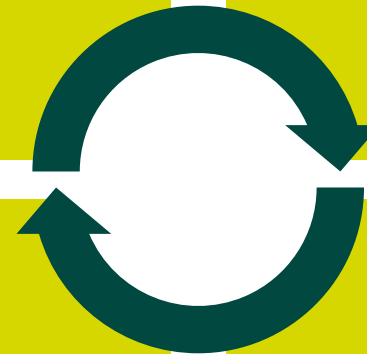
Interface towards federal authorities (UVEK, BFE, ElCom)

Statements and regulatory proposals

Association work

Publications and media appearances

Strategic analysis

Research collaborations
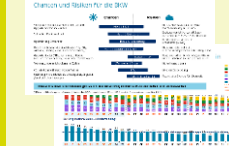
Deep dives and ad-hoc analyses
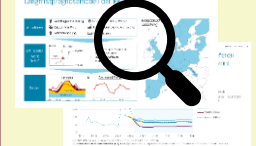
Long-term price prognosis (LPP)

Long-term price prognosis (LPP) BKW

Assumptions

- 🔌 Demand development
- ☀️ Expansion PV & wind
- ⚡ Grid development 🔍
- 🔥 Gas-, coal & CO$_2$ prices
- 🏭 Thermal power plant stack
- 🔋 Flexibilities

LPP model (merit order)

Cost — Demand — Supply — **Price** — Volume

- – Hourly resolution
- – **Until 2050**
- – 3 commodity price scenarios
- – 18 weather scenarios

Output

Dispatch   &   Day-ahead Preise

Demand — Flex — Renewables — Baseload production

00:00 06:00 12:00 18:00

00:00 06:00 12:00 18:00

Geographical coverage
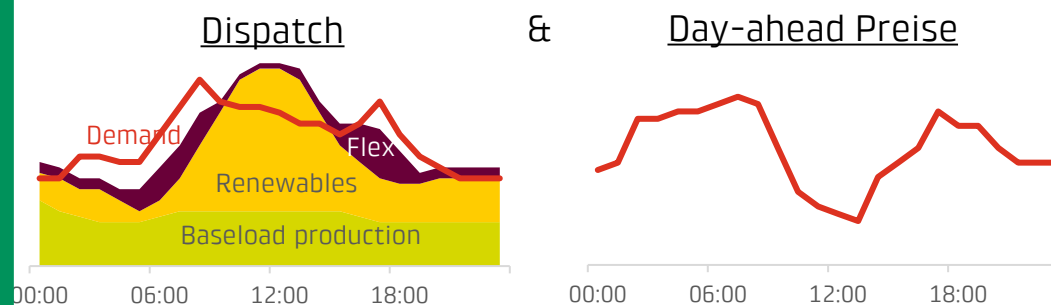
Our long-term flow-based market coupling modeling journey
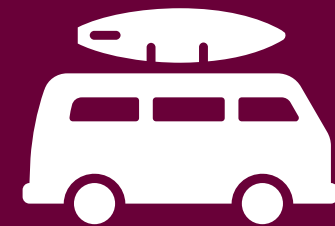
Our beginnings…

The long-term FBMC modeling journey – timeline

Understanding flow-based market coupling mechanism and application to short-term models

Our beginnings...

Where we stand now...

The road ahead...

How does flow-based market coupling (FBMC) work?

Net transfer capacity (NTC) domain

- NTC limits: static import and export limit for every border

- Market result A:
  - Capacity in A➜B direction is used fully, no exchange in direction A➜C
  - Regardless of exchange in A➜C direction, more exchange in A➜B direction is not allowed

Flow-based market coupling domain

- FBMC limits: line = critical network element contingency (CNEC). These critical elements should not be overloaded!

- Market result A:
  - More transaction in A➜B direction is allowed if there is negative transaction in A➜C direction

Graphic sources: Introduction to Core FBMC 2022

How does flow-based market coupling (FBMC) work?

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Switch from «FB Plain» to «Extended LTA Approach» in 2022

Graphic sources: Introduction to Core FBMC 2022   LTA = long-term allocation

How to integrate FBMC in short-term modeling?

Replication of Euphemia day-ahead market clearing

— Remaining availability margin (RAM) constraints of CNECs can be **modeled as condition matrix** to welfare optimization problem together with bidding zone balance equations, LTA formulation etc.

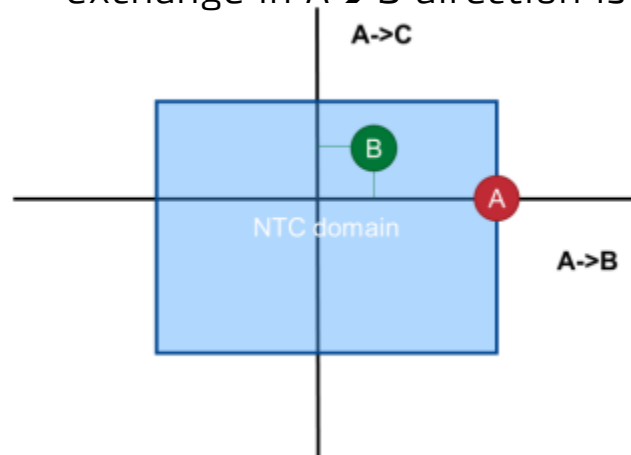**Options to forecast of FBMC data sets for future days**

— **Historical drawing**

  — Create similarity ranking based on (time-)weighted feature differences of future target and past hours (e.g. wind generation, consumption etc.)

  — Choose PTDFs from similar hours in the past

  — Run prediction model for most similar PTDF data sets (e.g. 10-20 runs)

— **Clustering approach**

  — Create new representative PTDF data set based on clusters centroids

$$\sum_{i \in Orders(l)} Q^i x_i = netpos_l$$

$$0 \leq x_i \leq 1$$

$$\alpha_1 \sum_l ptdf_{m,l} \; netpos_l^{FB} \leq \; \alpha_1 RAM_m$$

The «Euphemia» Matrix

Equation sources: Link   BZ = bidding zone   BEX = bilateral exchange   PTDF = power transmission distribution factor

The long-term FBMC modeling journey – timeline

Facing the challenges appyling the flow-based market coupling modeling to long-term time horizons

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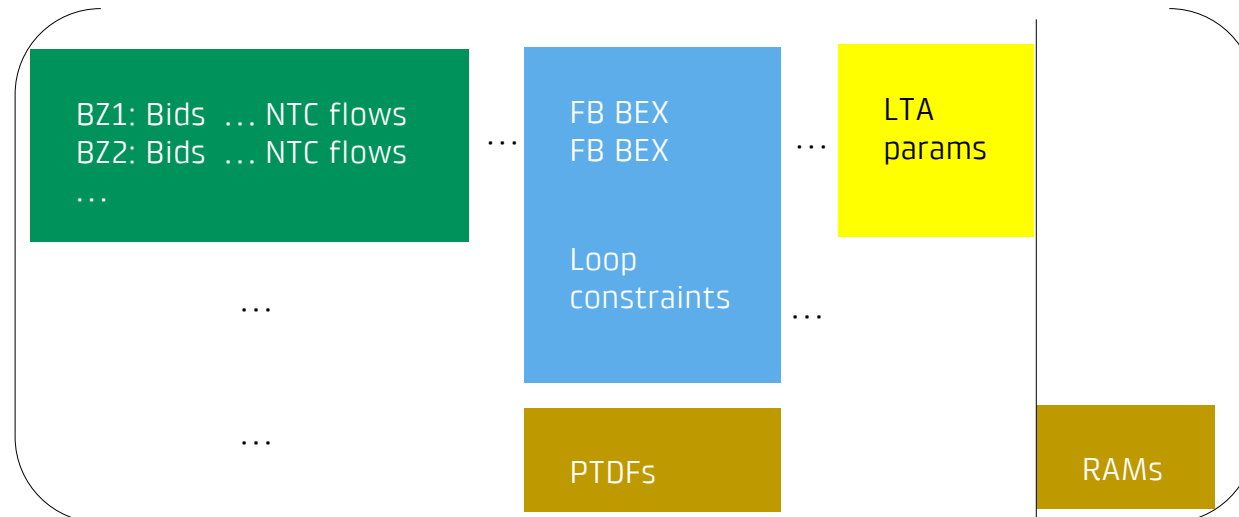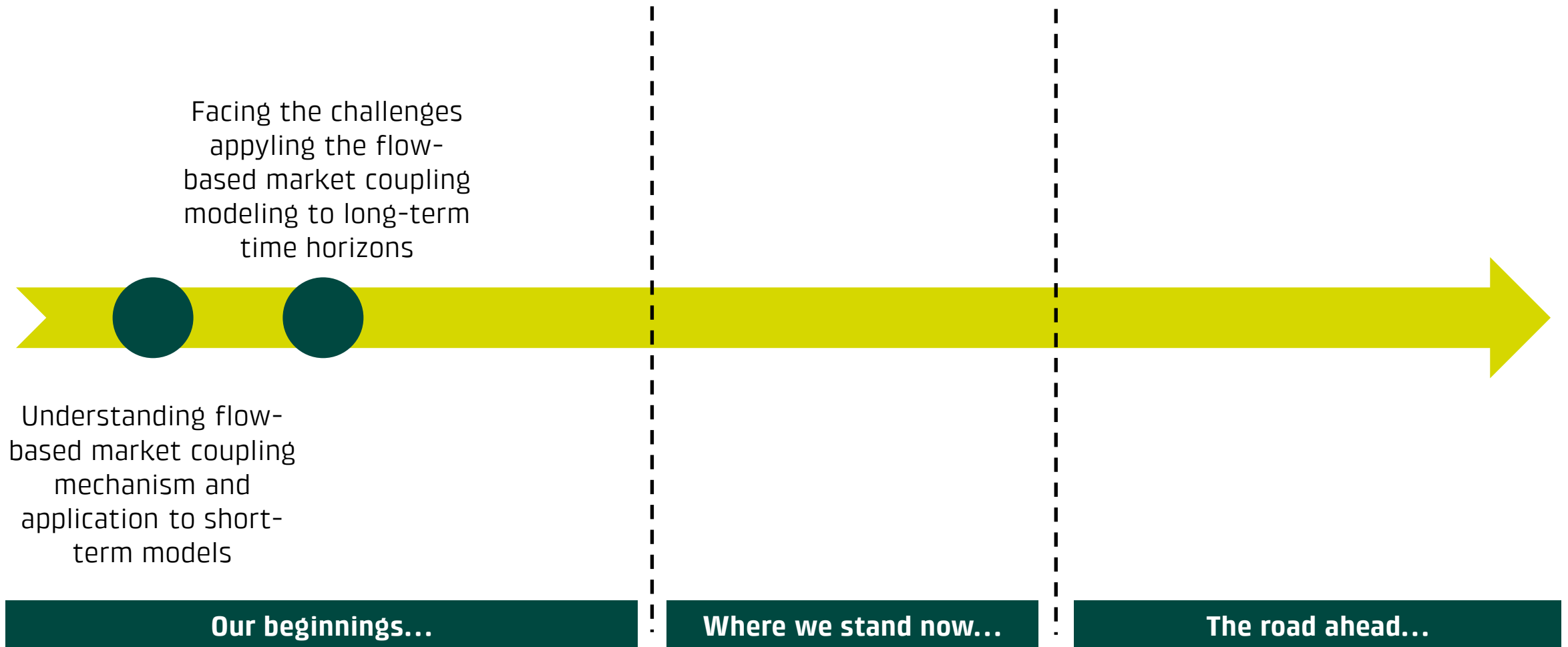
What challenges do we face with FBMC in long-term modeling?

Initial situation:

Huge effort to maintain a pan-European **physical power flow model**

– Utilities typically work with **fundamental market models** instead

– **Critical network elements cannot be determined directly in the model by N-1 security simulations for a specific load flow scenario**

Resulting challenges:

Difficulty in estimating correct FB parameter sets until 2050

Grid expansion

Structural breaks in the data due to geographical FBMC expansion and the addition of extra HVDC elements

Computational complexity / run time issues

Regulatory framework changes
(minRAM rules, region specific tweaks (AMR, IVA …) etc.)

No further background information available about CNECs for a particular hour
(only numerical values)

Low robustness of predictions due to binary PTDF selection

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NTC approach and taking into consideration dominant fundamental parameter effects

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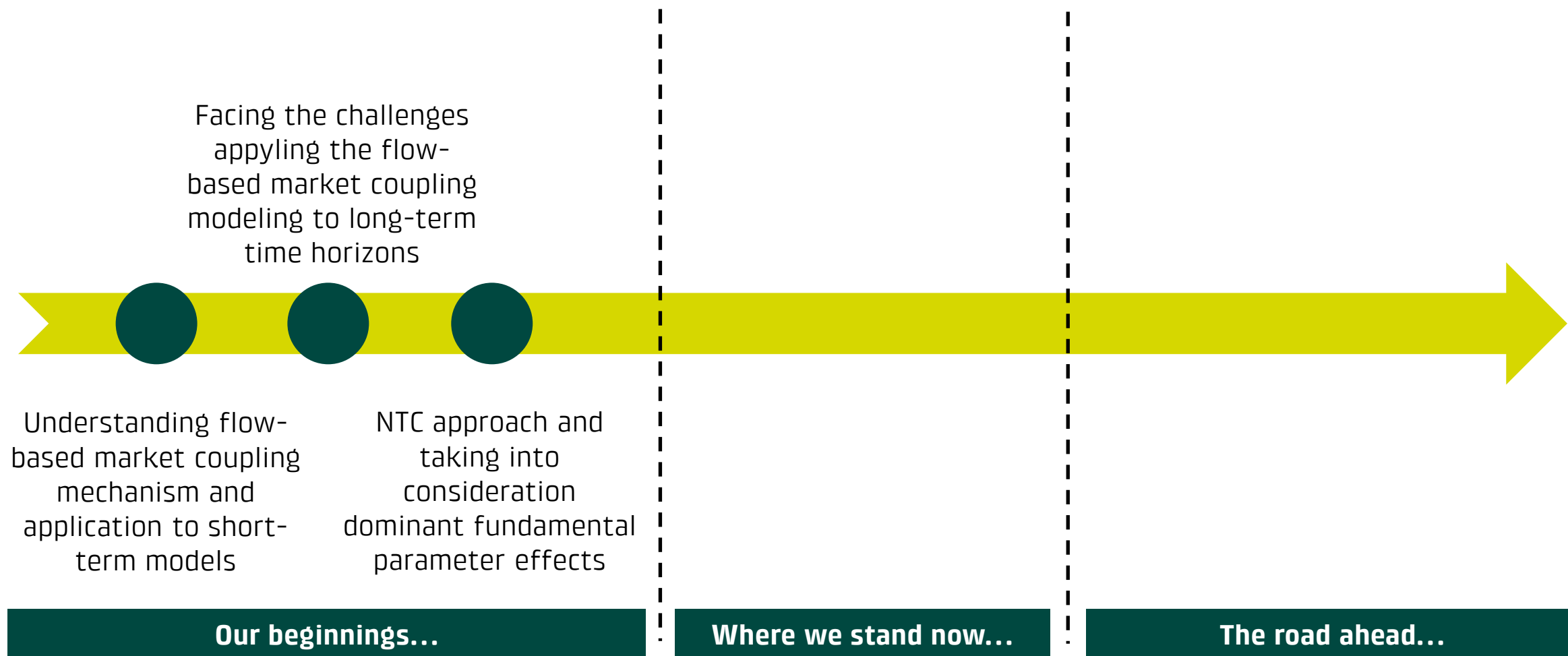
Identifying first important drivers for FBMC data sets

German wind onshore generation – MaxBex correlations
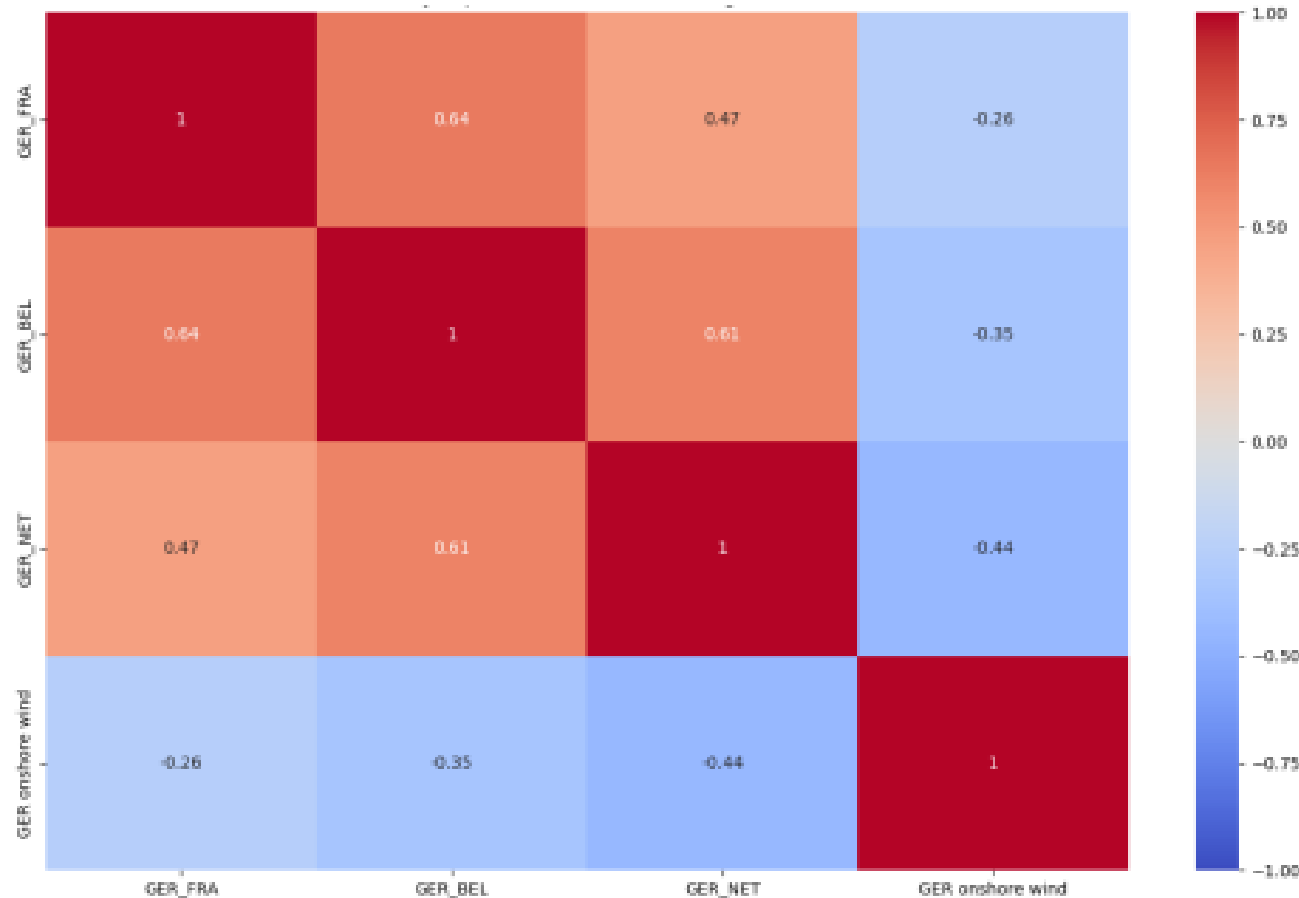
- – **Starting point** was a fundamental **model where all interconnectors were modeled as NTC borders**

  In a next step, **clear relationships between maximum possible FBMC flows and fundamental data sets were identified**.

- – High wind generation in Germany reduces maximum exports (grid congestion)
- – Higher base consumption results in lower export capacities on weekdays (BEL-FRA, GER-POL, GER-FRA)
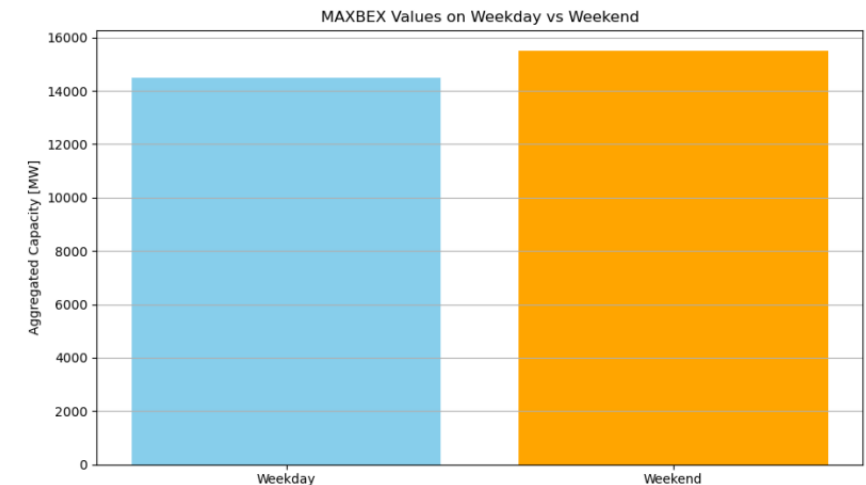
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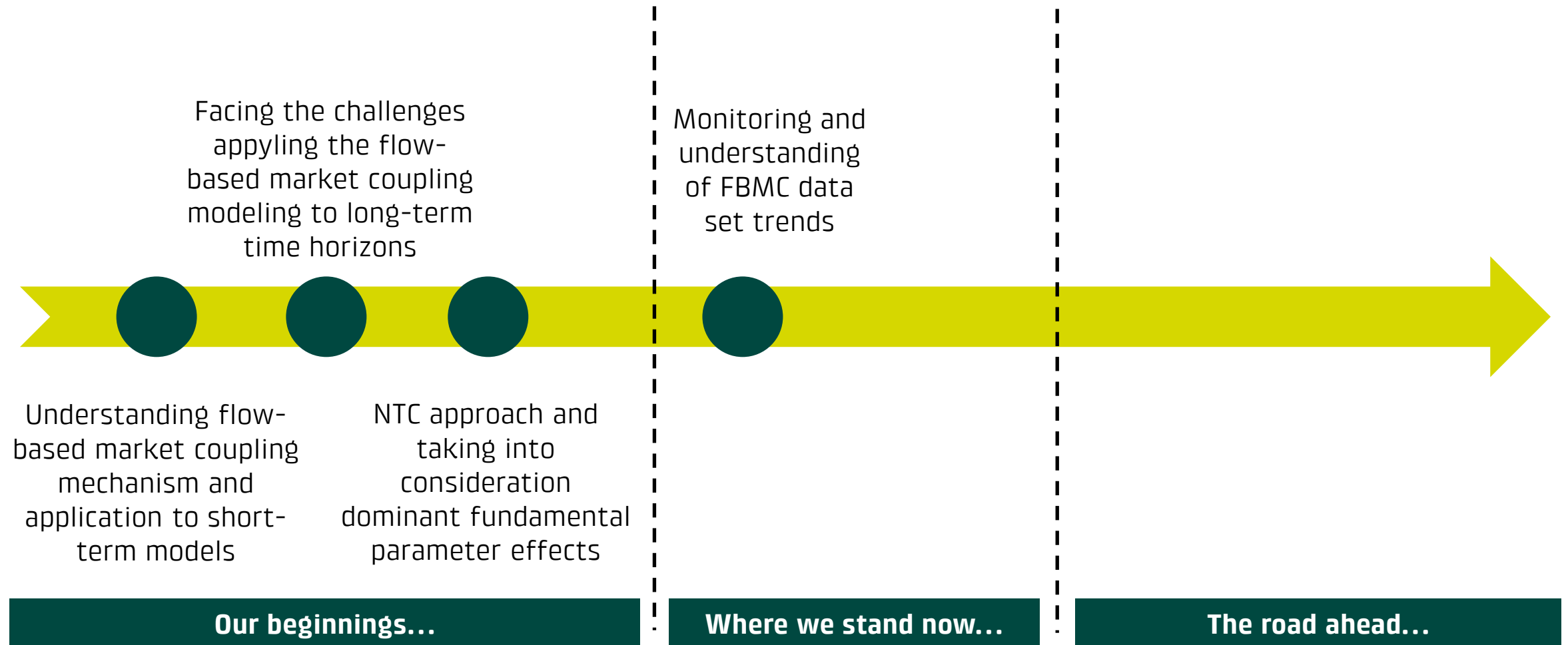
Monitoring the FBMC data set trends –
Do grid bottlenecks slowly disappear?

— Many FBMC parameter sets can easily be accessed via PuTo Core CCR

— Systematic tracking of the **RAM available in the day-ahead market** for critical grid elements indicates **that progress is being made in grid expansion in Europe.**

— A value of 1 corresponds to permanently perfect availability of network elements in a country in accordance with their technical specifications.

minRAM (= (RAM + FLTN) / FMAX) Evolution Analysis for Flow-based Countries

Year & Quantile
- 2023 Q25
- 2023 Q50
- 2023 Q75
- 2024 Q25
- 2024 Q50
- 2024 Q75
- 2025 Q25
- 2025 Q50
- 2025 Q75
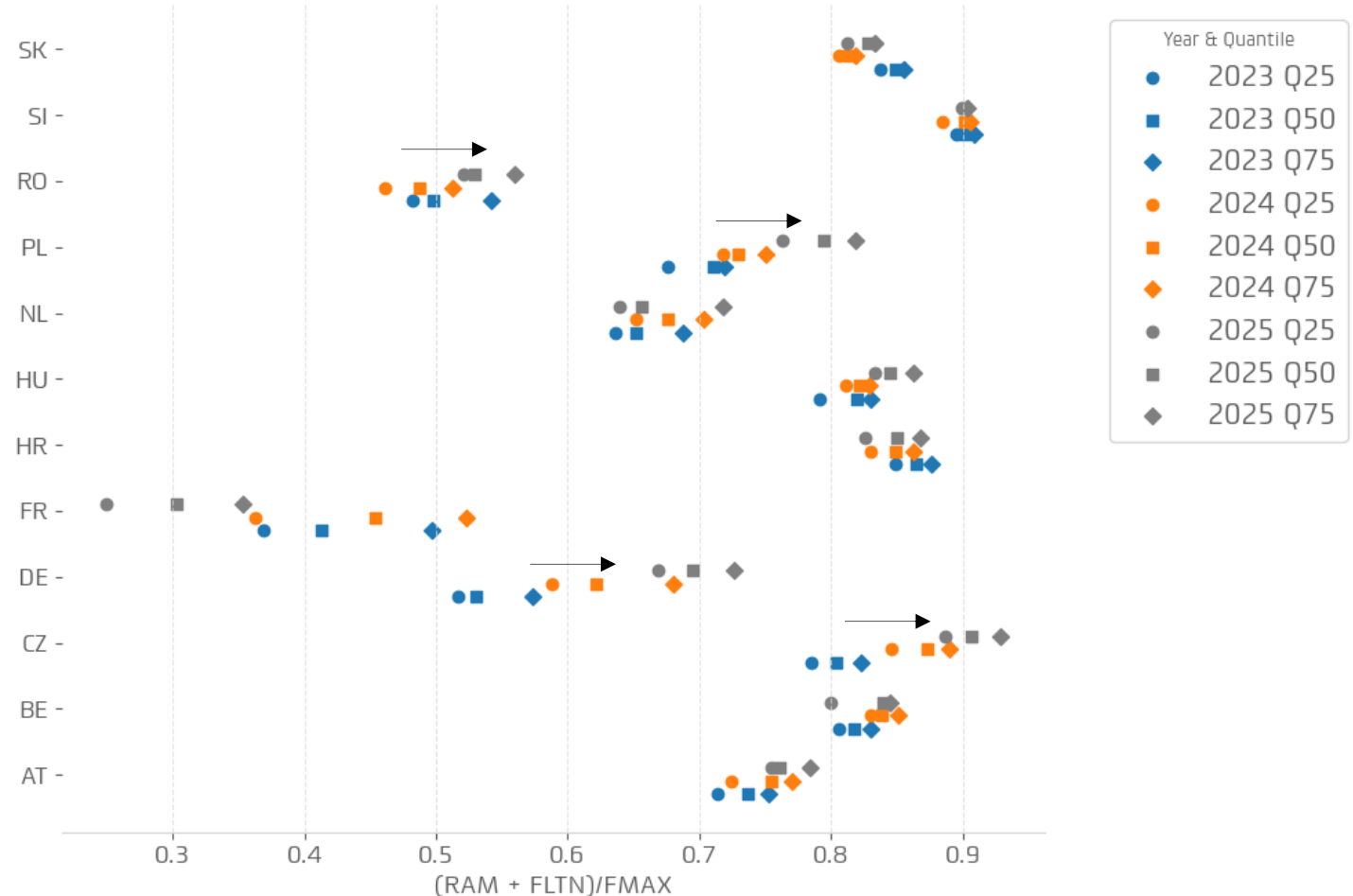
Monitoring the FBMC data set trends –
Is the LTA extension becoming less important?

Typical Hourly Alpha Factor per Year

Typical Monthly Alpha Factor per Year
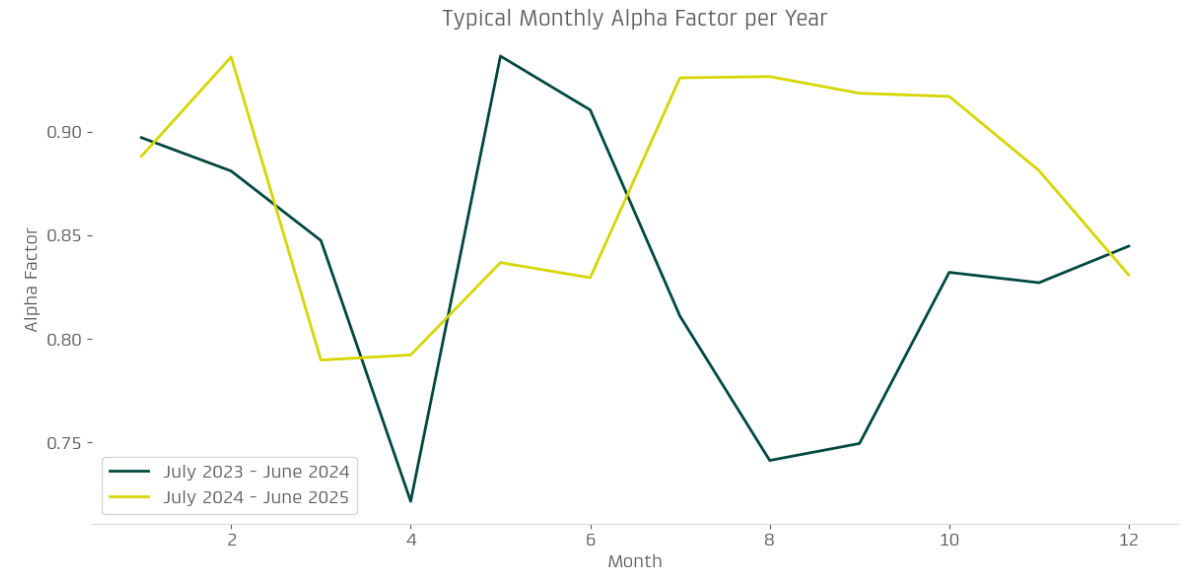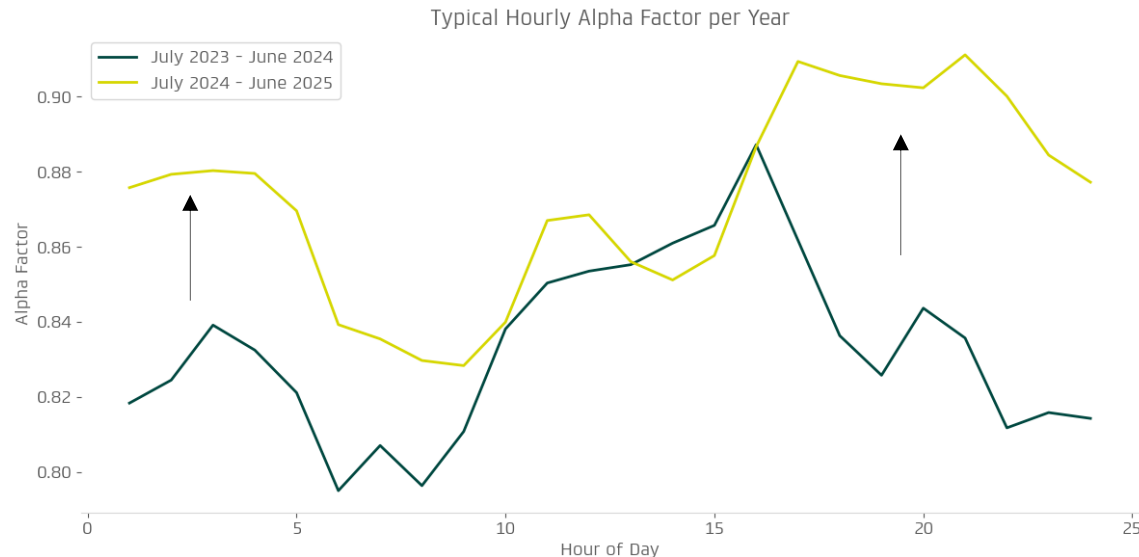
– An alpha factor of 1 means that the solution was found entirely in the FB domain and no LTA extension was active.

– **Alpha factors tend to be lower in spring periods** (March/April)

– In general, there seems to be a trend toward fewer hours in which alpha factors that deviate significantly from 1.

➤ **Such structural trends in RAM usage and LTA domain usage should be incorporated into our FBMC approximation model**.

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Systematic usage of machine learning model

Our beginnings…

Where we stand now…

The road ahead…

Systematic usage of machine learning models for shaping cross-border capacity profiles

Input data set structure for cross-border capacity prediction

FBMC data trend inputs
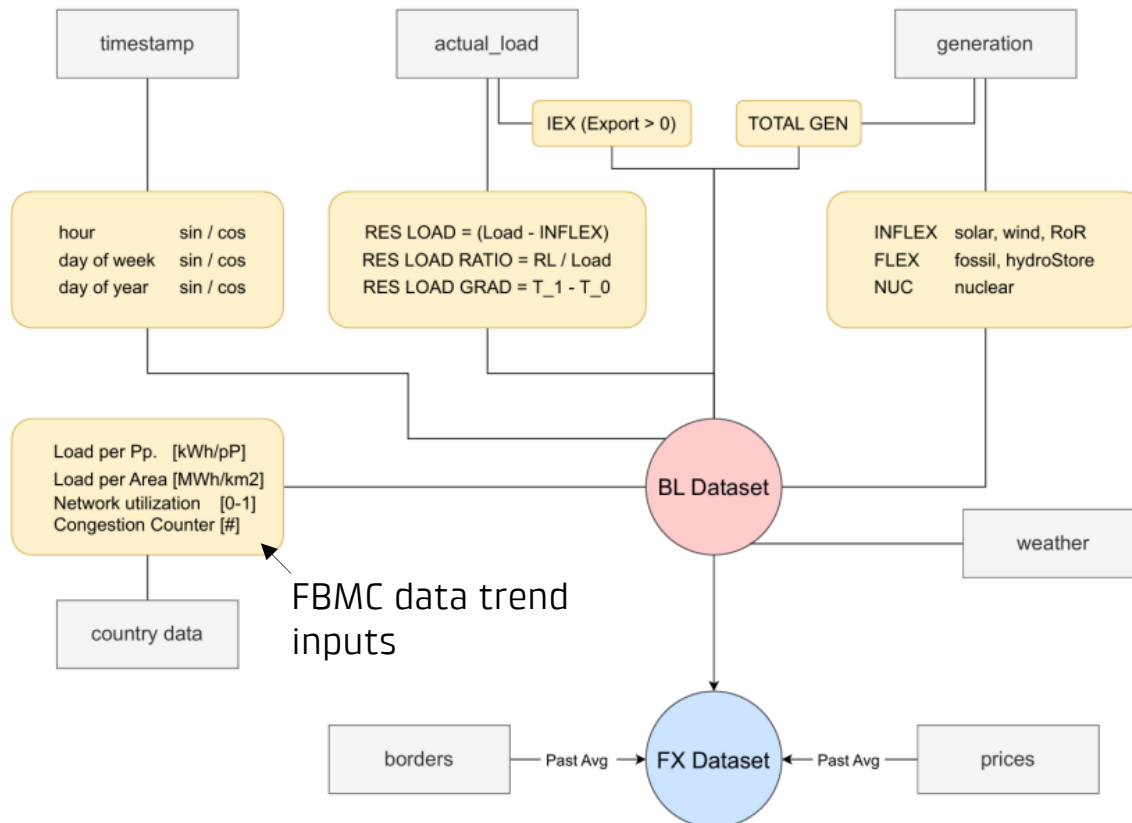
- **Goal:** machine learning model to approximate physical N-1 grid simulations of transmission system operators (TSOs)
  - approximate FBMC as hourly varying NTC values
- **Target variable**: hourly relative MaxBex variation
- Use principal component analysis (PCA) for input dimension reduction

Hybrid model architecture
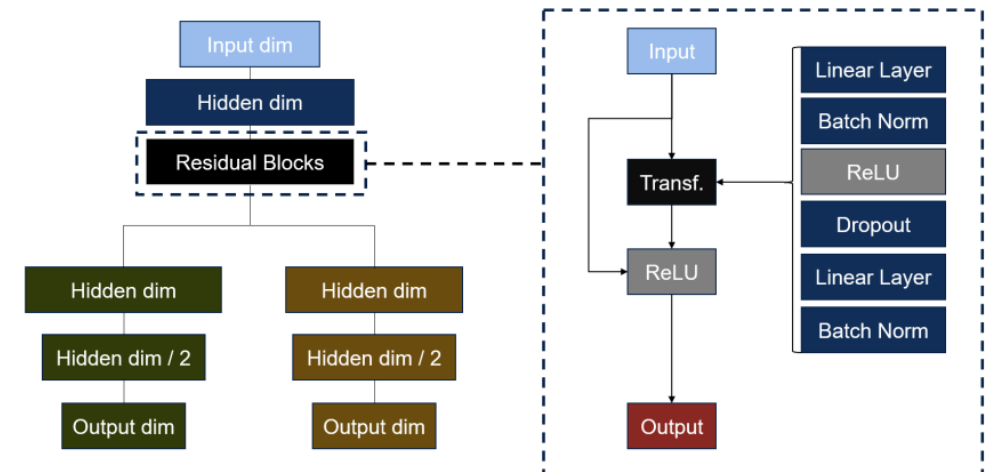
Historical backtest as quality assurance tool for new models
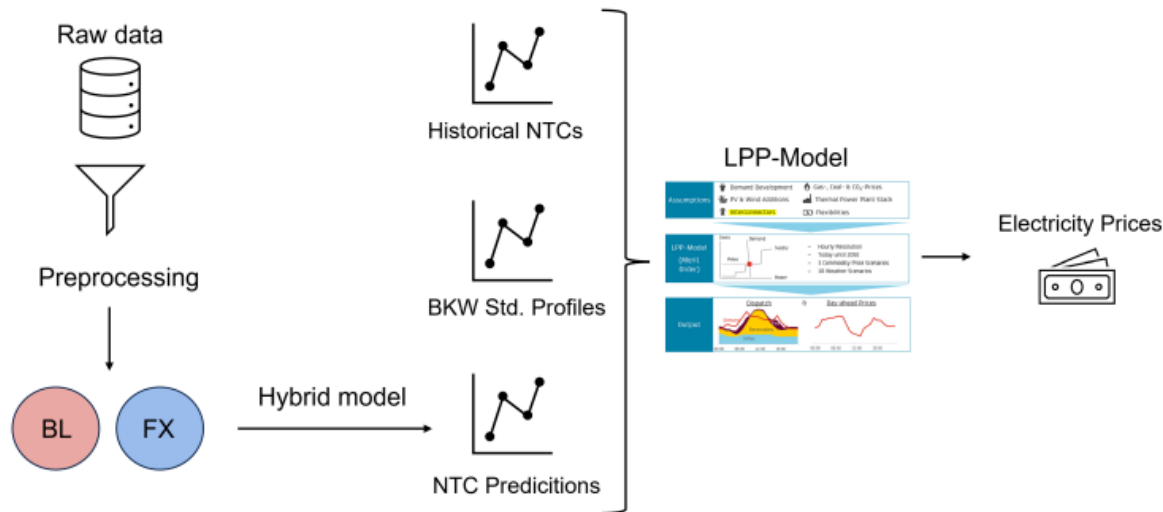
Model	Relative improvement
Previous standard future profiles	-
Hybrid model «Baseline»	15.2%
Hybrid model «Features Extended»	20.5%
Historical NTC / realized capacities	22.2%

- We can execute **historical backtest** with our LPP day-ahead market model

  - How well can historical **day-ahead prices** be matched when we use realized (weather, consumption etc.) data sets?

- Machine learning model **is applicable for shaping NTC and FBMC border capacity profiles.**

- **How do the backtesting results change when using different capacity profiles? (ceteris paribus)**

- Machine learning model improves pricing in backtesting. **The model therefore delivers better results than using the previous profiles, which only reflected selected fundamental relationships.**

The road ahead…

The long-term FBMC modeling journey – timeline

Facing the challenges appyling the flow-based market coupling modeling to long-term time horizons

Monitoring and understanding of FBMC data set trends

Keeping up with academic literature

Understanding flow-based market coupling mechanism and application to short-term models

NTC approach and taking into consideration dominant fundamental parameter effects

Systematic usage of machine learning model

Our beginnings…

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The road ahead…

Literature review – how could we enhance our current long-term modeling approach?

Modeling methodologies

– **Approximating the flow-based domain for long-term market analysis in hydropower-dominated power systems (2023)**

  – Link

Curent and future market design developments

– **Introducing advanced hybrid coupling: Non-discriminatory coalescence of flow-based and net transfer capacity calculation regions (2024)**

  – Link

– **Improving flow-based market coupling by integrating redispatch potential—Evidence from a large-scale model (2024)**

  – Link

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Deep-dive into transmission outage data sets

Our beginnings…

Where we stand now…

The road ahead…

How to successfully integrate transmission outages in modeling?

— Model results show that there are certain phases **where we obviously miss important information.**

— One obvious data set that has not yet been used for forecasting is **transmission system outages.**

— **Challenge – How to create a complete and correct transmission outage data set?**

    — Not yet 100% happy with Entso-E [Transparency Platform](#)

💬 **Do you know other sources? How do you tackle this challenge?**

Actual vs Predicted Capacity BL_FBMC_NORM - GER_AUS
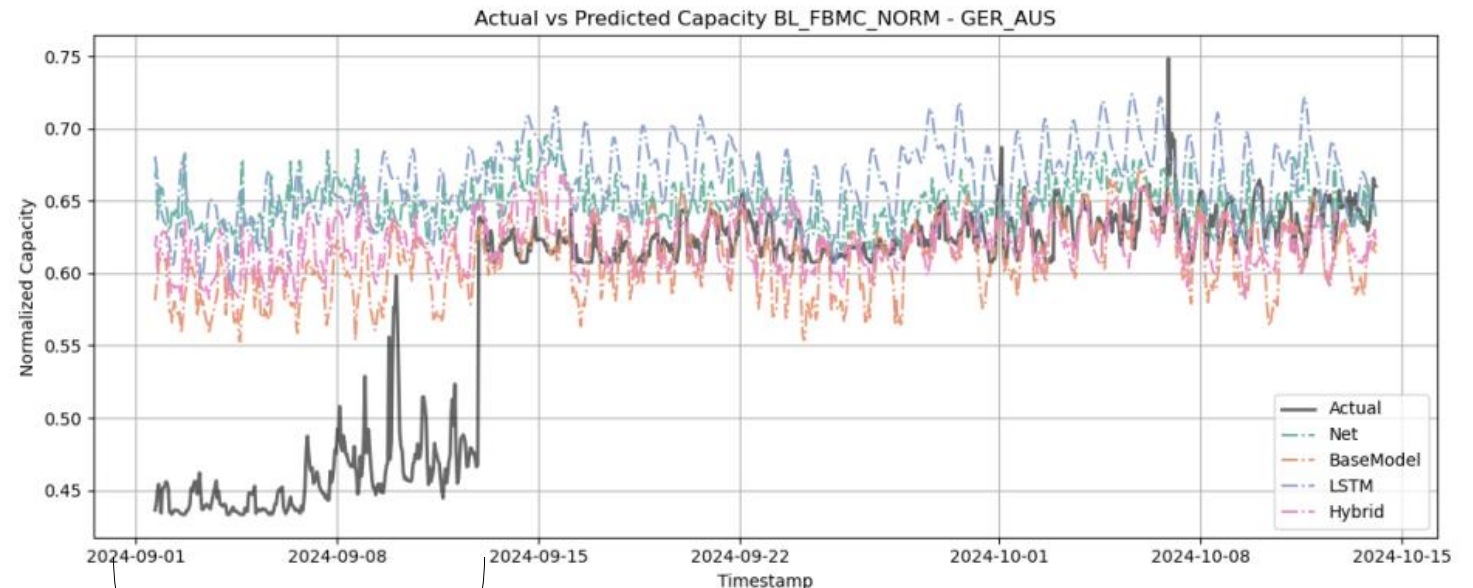
What happened here? ❓

The long-term FBMC modeling journey – timeline

Facing the challenges
appyling the flow-
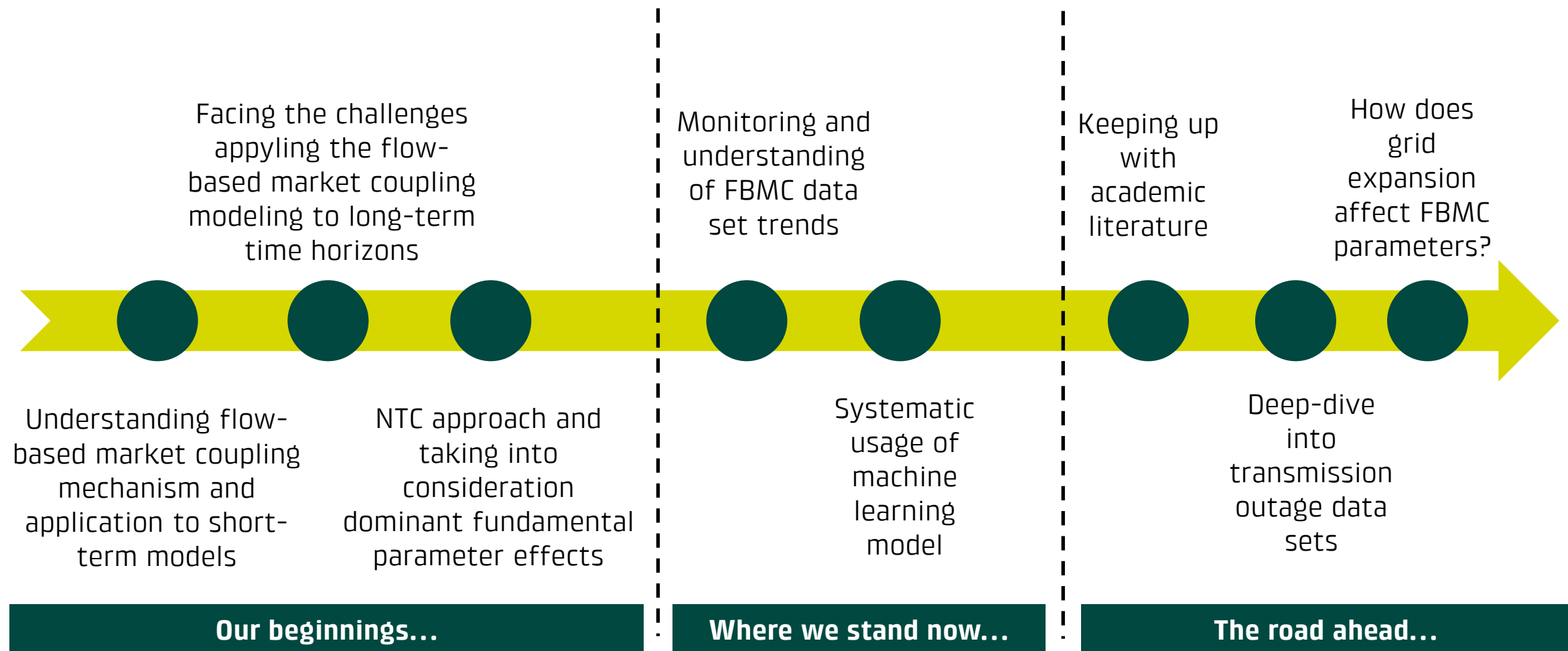based market coupling
modeling to long-term
time horizons

Monitoring and
understanding
of FBMC data
set trends

Keeping up
with
academic
literature

How does
grid
expansion
affect FBMC
parameters?

Understanding flow-
based market coupling
mechanism and
application to short-
term models

NTC approach and
taking into
consideration
dominant fundamental
parameter effects

Systematic
usage of
machine
learning
model

Deep-dive
into
transmission
outage data
sets

Our beginnings…   **Where we stand now…**   **The road ahead…**
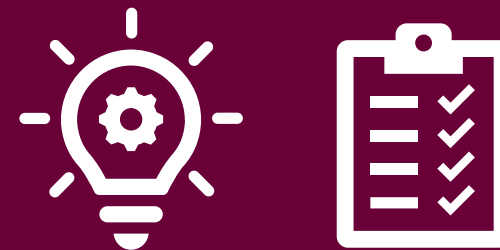
How will future grid expansion affect FBMC parameter sets?

— **Which future transmission projects will be implemented with what delay?**

    — Systematic model developed

        — **Delay**

            — based on TYNDP project state

        — **Probability**

            — based on historic TYNDP project tracking and financials (CAPEX vs congestion rent)

— **How does a new transmission project affect the flow-based parameter sets?**

    — Can we deduce the PTDF impact by analysing historical changes in the date set before and after the go-live of transmission projects?

    — Can we apply the findings to future projects?

TYNDP = Ten year network development plan Entso-E

Cross-Border Export Capacity for the Border Direction AT-DE
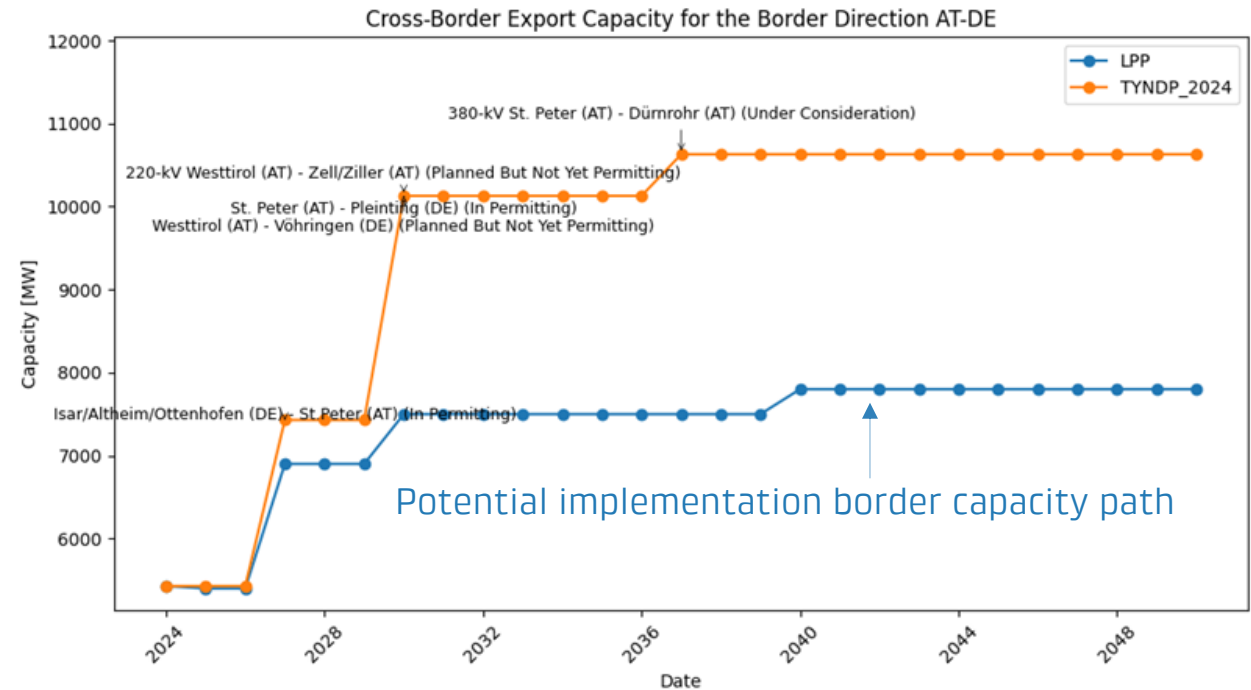
Summary & conclusion

What key messages to take away from the presentation?

- We do not aim to forecast FBMC parameter sets directly up to the year 2050, but instead concentrate on the **key factors influencing the possible maximum transmission capacities modeled as hourly NTCs**.

- **Machine learning** models are suitable for **translating fundamental power system data sets and FBMC parameter trends into simplified NTC constraints** and enhancing power price model performance.

- Since the **power system is in a state of constant change**, continuous **monitoring** of the realized cross-border flows and flow-based parameters is inevitable.

- To further **improve the quality of long-term forecasts**, we are focusing on **gaining a deep understanding of how transmission grid expansion and maintenances affect FBMC parameters.**

- In addition to understanding how grid expansion and transmission capacities interact in the FBMC regime, it is very important for us **to assess where the grid will actually be expanded by 2050 and beyond**.

- For borders with significant **uncertainties (e.g. will Switzerland join the FBMC in the context of a potential electricity agreement with the EU?**), power plant investment business cases must always be evaluated using a **range of scenarios**. **In addition to weather and fuel price scenarios, transmission capacity scenarios should therefore also be included in the corresponding scenario set.**

- We have definitely **not yet achieved all of our goals** in this area, and I would be **delighted to hear your thoughts on the topic today and tomorrow.** I look forward to talking to you!

Email: fabian.gottschlich@bkw.ch   Linkedin: Link

Vielen Dank für Ihre Aufmerksamkeit

Fabian Gottschlich
Head of Strategic Market Analysis

BKW Energy

Backup

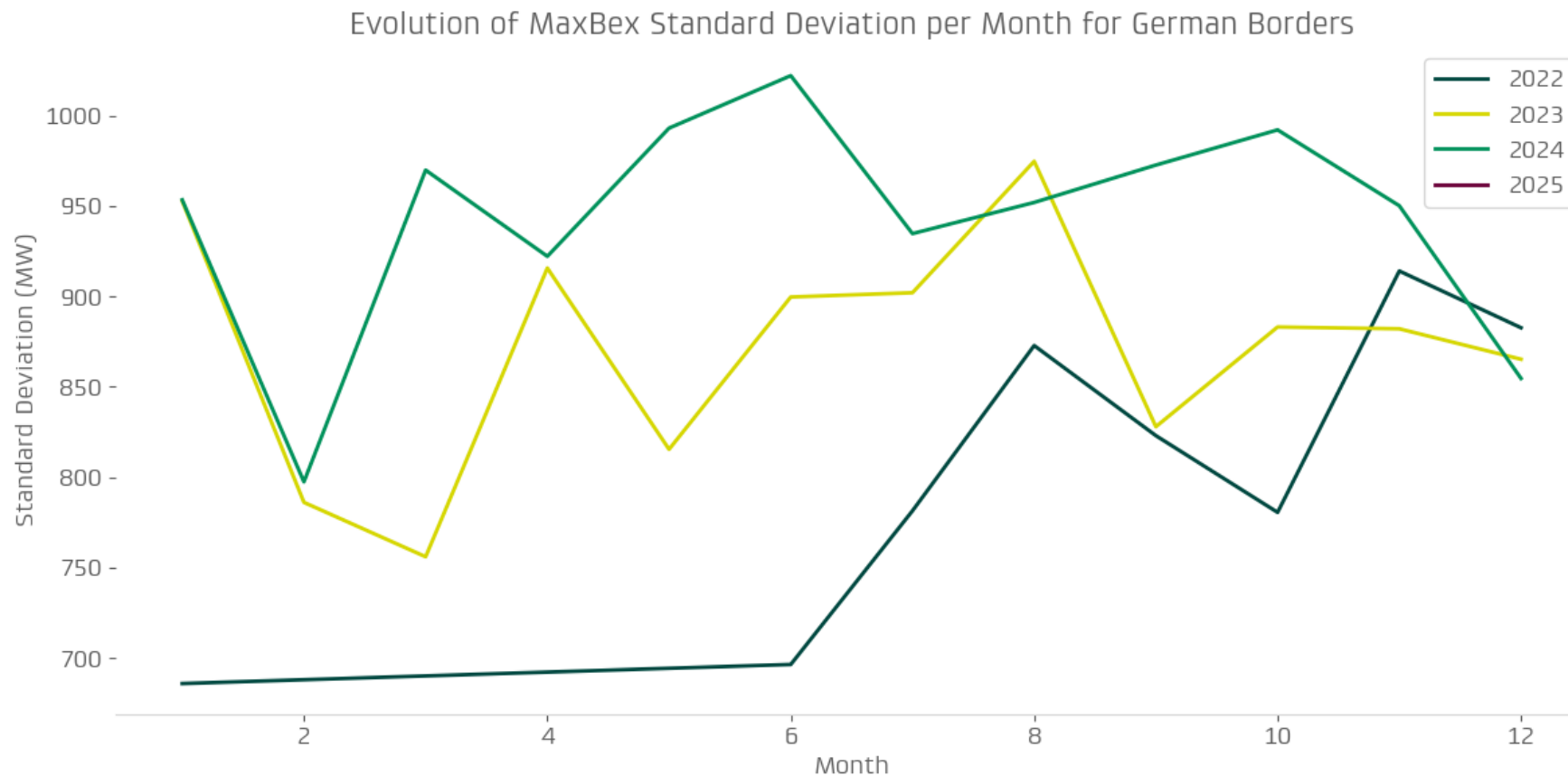# Machine learning model – neighbouring country features

(a) Spain to Portugal, resulting in 103 feature columns.

(b) Germany to France, resulting in 349 feature columns.

X

Monitoring the FBMC data set trends –
How does MaxBex standard deviation change over time?

Evolution of MaxBex Standard Deviation per Month for German Borders

Monitoring the FBMC data set trends – External allocation constraints Poland

Poland External Allocation Constraints - Import

Poland External Allocation Constraints - Export
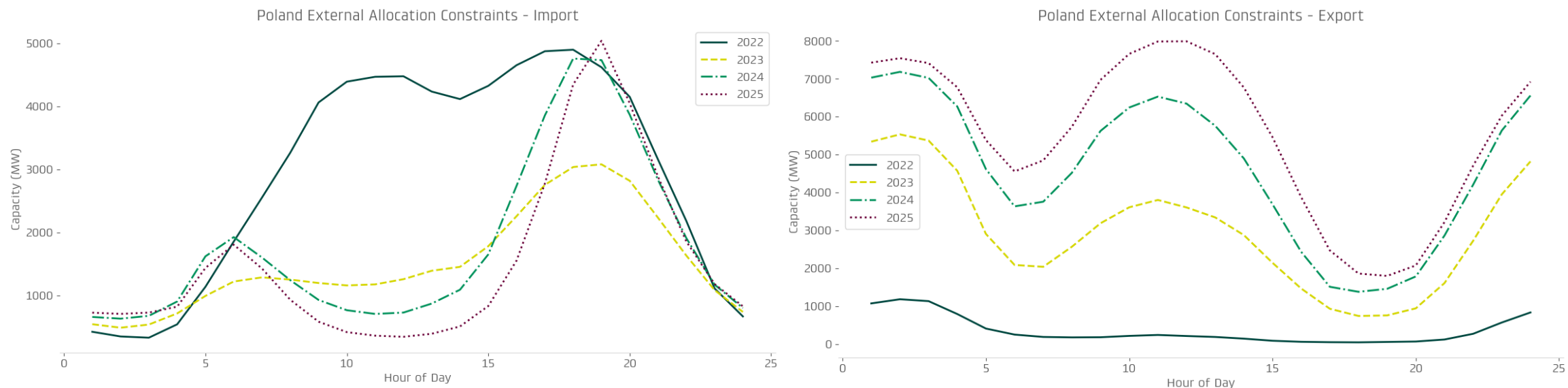
- Loop flows (especially in windy periods) as one of the reasons for the introduction of Polish allocation constraints
- Polish exports were heavily restricted throughout energy crisis in 2022
- Generally clear trend towards higher allowed Polish exports